PERFORMANCE OF SLASH PINE (*Pinus elliottii* Engelm.) CONTAINERIZED ROOTED CUTTINGS AND BARE-ROOT SEEDLINGS ESTABLISHED ON FIVE PLANTING DATES IN THE FLATLANDS OF WESTERN LOUISIANA

A Dissertation

by

ALPER AKGÜL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2004

Major Subject: Forestry

PERFORMANCE OF SLASH PINE (*Pinus elliottii* Engelm.)

CONTAINERIZED ROOTED CUTTINGS AND BARE-ROOT

SEEDLINGS ESTABLISHED ON FIVE PLANTING DATES IN THE

FLATLANDS OF WESTERN LOUISIANA

A Dissertation

by

ALPER AKGÜL

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Approved to the style and content by:

Michael G. Messina (Chair of Committee)	David D. Briske (Member)
Mark G. Tjoelker (Member)	Todd Watson (Member)
Eric Taylor (Member)	Charles T. Smith (Head of Department)

May 2004

Major Subject: Forestry

ABSTRACT

Performance of Slash Pine (*Pinus elliottii* Engelm.) Containerized Rooted Cuttings and Bare-root Seedlings Established on Five Planting Dates in the Flatlands of Western Louisiana (May 2004)

Alper Akgül, B.Sc., Istanbul University;
M.S., Ege University
Chair of Advisory Committee: Dr. Mike Messina

The forest product industry is keenly interested in extending the normal planting season, as well as in the comparative field performance of standard nursery bare-root seedlings and containerized rooted cuttings. The effect of seasonal planting dates on survival, above and belowground biomass allocation, water relations, gas exchange attributes and foliar carbon isotope composition ($\delta^{13}C$) of two stock types of slash pine (*Pinus elliottii* Engelm.) were examined. Slash pine bare-root seedlings (BRS) and containerized rooted cuttings (CRC) were hand planted in September, November, January, March and April in three consecutive planting seasons (2000-2001, 2001-2002 and 2002-2003) on three sites with silt loam topsoils in southwestern Louisiana. First-year mean survival of CRC across all planting dates and sites was consistently high at 96 to 98%, whereas BRS survival was significantly ($P < 0.0001$) lower at 59 to 81% and highly variable among study sites and dates through three planting seasons. Generally, there was a negative relationship between soil moisture at the time of planting and first-year survival of BRS planted September through March in 2001-2002 and 2002-2003 planting seasons, whereas the opposite was observed only for BRS planted in April 2002 and 2003. Survival of CRC was affected very little by the variation in soil moisture.

Containerized rooted cuttings had higher early above and belowground biomass, and height and diameter than did BRS. However, three years after planting the size differences between stock types disappeared or became negligible. Early size differences among trees planted September through March also decreased after three years, although September trees were tallest. Growth of the April-planted trees was poor compared to trees planted in other months.

Late-planted April trees had higher $\delta^{13}C$ values, and higher water-use efficiency in the first growing season compared to earlier planted trees. Differences in $\delta^{13}C$ values among the planting dates disappeared in the second growing season. Net photosynthesis rates did not differ considerably between stock types or among planting dates in the second and third growing seasons. This study indicates that it is possible to extend the planting season to as early as September and as late as March by using CRC.

ACKNOWLEDGEMENTS

I would like to acknowledge the following individuals and institutions for their contribution to this dissertation:

Dr. Michael G. Messina, chair of my Advisory Committee, for giving me the opportunity to work on this interesting project, for offering me a research assistantship position, for all his wisdom, guidance, and continuous support in the past four years.

Dr. David D. Briske, for being member of my committee, for his excellent RLEM 607 course, which deepened my knowledge and interest in plant ecophysiology, and for all advice provided.

Dr. Mark G. Tjoelker for all his invaluable contributions with his ideas and suggestions, for being member of my committee, for his FRSC 601 course which I found very interesting and which increased my knowledge in forest ecosystems and global change and for all the support and advice provided.

Dr. W. Todd Watson, for serving on my committee, for all his advice, encouragement and support.

Dr. Eric L. Taylor, for his kind assistance with my fieldwork, serving on my committee, and all his advice.

The Department of Forest Science for all the support provided for the project.

Tim Rogers, Dr. Mohd Rahman, Ben McKay, Dr. João C. Azevedo, Amir Hass, Hakan Oğuz, Wael Jabr, Dr. Jennifer Myzewski, for all the friendship, support and assistance.

Necdet Karakurt, Dennis Transue, Darren Hibbs, John Donley, Thomas Stvdlinski and all the student workers for traveling with me to Louisiana and helping me with my field work.

Laverne Addison, Marilyn Seymour, Gloria Norman, Lesli Gomez, Suzie Billings, Gail Hyden, Shay Harman and Dr. Zhiyong Cai for their amicable assistance.

Alicia Kerr, for her time and suggestions in preparation of this dissertation.

Boise Corporation for financial support and field help provided.

Alan Wilson, Joe Weber, Ronnie Fontenot, Bruce Franks, Leonard Thomson, Wayne Masur, Jim McKnight and other Boise personnel for their help in planting trees, fertilization of plots, and all the drinks that they provided on hot planting days.

Dr. Nazimi Açıkgöz, Dr. Habil Çolakoğlu, Dr. Doğanay Tolunay, Dr. Hidayet Karakurt, Dr. Bünyamin Doğan, Yılmaz Güngör, Gürdeniz Gönül and all Izmir Forest Soil Laboratory personnel for their support and encouragement during my research assistantship application process.

My family, who have supported me with their continual encouragement, and particularly my father, Bekir Akgül, for his love of nature which was contagious.

My wife, Jayne Peck Akgül, for her never-ending patience, support, and encouragement.

Finally, my daughter, İmge-Megan Akgül, for inspiring me with her smile.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

Page

CHAPTER I
INTRODUCTION

Slash pine (*Pinus elliottii* Engelm.) is one of the most commercially important pine species in the southern United States (Walker and Oswald 2000). It grows naturally from southern South Carolina to central Florida and west to eastern Louisiana, but has also been planted and direct-seeded in Louisiana and eastern Texas where it now reproduces naturally (Lohrey and Kossuth 1990). Slash pine's commercial importance makes it critical in the American forest product industry to achieve its sustainable forestry goals. Sustainable forestry consists of practices that meet present needs without compromising the ability of future generations to meet their own needs. Sustainable forestry combines the regenerating, growing, nurturing, and harvesting of trees to meet the demand for forest products while ensuring the protection of soil, water, air quality, wildlife and fish habitat, and landscape aesthetic quality (Jenkins and Johnson 1999). The Sustainable Forestry Initiative program (SFI), one of the largest sustainable forestry programs in the world, is a comprehensive system of principles, objectives and performance measures that integrate the continual growing and harvesting of trees with the protection of wildlife, plants, soil and water quality (American Forest and Paper Association 1998). Prompt, successful regeneration is one of the conditions required by the SFI membership in the American Forest and Paper Association (AF&PA 2001). Selecting a successful regeneration system is highly important to avoid time loss and unwanted additional costs (Dougherty and Duryea 1991).

Although southern pine seedlings are generally produced as bare-root stock, vegetative propagation, especially rooted cuttings, is becoming more common in forest regeneration (Weber and Stelzer 2000). Vegetative propagation can offer

---

This dissertation follows the style set by the Journal of Forest Science.

many advantages such as faster growth or better disease resistance by producing clones of donor trees (Greenwood et al. 1991). While there is ongoing research to develop useful technology for production of rooted cuttings, more information is needed about the field performance of this stock.

Containerized stock can increase planting success in various limiting environmental conditions by providing protection to roots during and following planting. South and Barnett (1986) reported that containerized loblolly pines with their intact root systems were able to overcome the transplanting shock, became established faster and survived better than bare-root stock when average soil moisture content (on a dry weight basis) at planting was as low as 10%. In a study with slash pine, seedlings grown in containers had 85% survival compared to that of seedlings (47%) removed from containers when planted in August in hot and dry conditions in South Carolina (Anderson et al. 1984). Sloan et al. (1987) found that after five growing seasons, containerized ponderosa pine (*Pinus ponderosa*) seedlings had significantly higher survival and growth than bare-root stock when planted on the harshest sites. Okafo and Hanover (1978) reported that transplant shock effect was greater for bare-root bigtooth aspen (*Populus tremuloides*) than for containerized stock. Boyer (1988) suggested that containerized longleaf pine might be more resistant than bare-root stock to the stresses caused by different factors like drought, competition, herbicide exposure and poor planting. He found that container stock had higher survival and growth compared to bare-root stock three years after planting in March.

Also, studies demonstrated that planting containerized stock can greatly extend the planting season (Barnett and McGilvray 1993). Marion and Alm (1986) found that planting season had no significant effect on survival of fall- and spring-planted container-grown red pine (*Pinus resinosa*) seedlings. Yet, bare-root stock had lower survival rates in fall planting compared to spring planting.

Barnett and McGilvray (1993) reported that March, April and May planted bare-root and container stock performed equally when planting conditions were ideal. However, container stock had higher survival and growth than bare-root stock when conditions were more stressful. Goodwin (1976) showed that containerized loblolly pine and longleaf pine (*Pinus palustris* Mill.) planted in July in North Carolina survived comparably to those of bare-root stock planted the following February. Three seasons later, containerized stock were significantly taller than bare-root stock (Goodwin 1976).

An extended planting season would enable landowners to better plan their regeneration activities throughout longer periods of available time. It may also allow replanting regeneration failures in the same year (Demers and Long 2000). An extended planting season makes wet sites accessible in the drier autumn period. Ponding of water for relatively long periods causes seedling mortality (Boyer 1988). On sites with perched water tables, planting during excessive wetness led to high mortalities, compared to planting after soil moisture declined. Yeiser and Paschke (1987) observed that loblolly pine (*Pinus taeda* L.) seedlings planted in February on a site with a perched water table had only 15% survival compared to 99% for those planted in May. They also reported that containerized loblolly pine seedling survival was 19% higher than that of bare-root seedlings on a site with a perched water table (Yeiser and Paschke 1987).

In this study, I investigated the field performance of slash pine bare-root seedlings (BRS) and containerized rooted cuttings (CRC) when planted on five different plantings dates in each of three planting seasons. Specifically, I tested the effects of planting stock type and planting dates on survival, growth (height, groundline stem diameter, above and belowground biomass accumulation) and physiological responses of slash pine trees as indicated by gas exchange measurements and carbon isotope composition ($\delta^{13}C$).

Chapter II discusses the early survival and height and diameter growth of BRS and CRC slash pine planted on different dates. Chapter III analyses physiological response and above and belowground biomass allocation.

CHAPTER II
CONTRASTING SURVIVAL AND GROWTH OF SLASH PINE (*Pinus elliottii* Engelm.) BARE-ROOT SEEDLINGS AND CONTAINERIZED ROOTED CUTTINGS

Introduction

Because of its rapid growth rate, slash pine is a valuable southern pine throughout the southeastern United States. It is a preferred source of pulp, and its strong, heavy wood is excellent for construction. Because of its high resin content, the wood is also used for railroad ties, poles, and pilings (McCulley 1950, Sheffield et al. 1983, Duncan and Duncan 1988, McCune 1988, Lohrey and Kossuth 1990).

Originally restricted to three million hectares, slash pine's range has been extended by planting to more than five million hectares at present (Ezell and Moorhead 2000). Bare-root planting stock is primarily used for planting the southern pines (Brissette et al. 1983, Barnett and Brissette 1986), and this is normally restricted to the dormant season of late November through early March to ensure survival through reduced planting shock that might lead to poor survival. This season may be extended under varying circumstances (Long 1991) and might change from year to year. There is also an escalating interest in using rooted cuttings as planting stock for pines (Stelzer et al. 1998). Vegetative propagation can deliver planting stock of higher genetic quality that may increase yield and shorten rotations (Weber and Stelzer 2000). However, research to date on the relative performance of rooted cuttings and bare-root southern pine seedlings have yielded mixed results (Foster et al. 1987, Stelzer et al. 1998). Rooted cuttings can be grown either as containerized or bare-root stock. Many studies have shown that containerized stock survive and grow better than bare-root stock (Mann 1977, Guldin 1981, Barnett 1984, Shaw 1985, Boyer 1988, Barnett and McGilvray 1993). Containerized stock is superior to bare-root stock, especially on the harshest sites under stressful conditions (Anderson et al. 1984, South and Barnett 1986, Sloan et al. 1987, Yeiser and Paschke 1987). Planting containerized stock can also greatly extend the planting season (Aycock, 1974, Goodwin 1980, Barnett and McGilvray 1993) to year-round in some cases (Malinauskas and Sukhotskas 1996). Survival and growth of transplanted seedlings depend on their ability to resist environmental stresses like cold, drought, mechanical handling, and their ability to establish root contact with the soil (Tinus et al 2000). Improved survival and growth of containerized stock is generally attributed to their intact root systems, compared to root systems of bare-root seedlings damaged by lifting; thus, containerized seedlings have a shorter period of transplanting shock or adjustment (Barnett and McGilvray 2000). Trees planted earlier can be larger after the first growing season than those planted at the "normal" time (Dierauf 1976).

Using slash pine containerized rooted cuttings might extend the planting season and perhaps provide early growth advantage if planted earlier. However, information is lacking regarding side-by-side comparison of field performance of containerized rooted cuttings and bare-root seedlings of slash pine in the West Gulf.

The objective of this study was to compare the survival and growth of slash pine bare-root seedlings and containerized rooted cuttings when planted on five different planting dates repeated annually through three planting seasons in order to experimentally test the extended planting window.

Methods and Materials

Study Sites

Three locations in an 11-km radius area in southwestern Louisiana were selected for this study (30° 33’ N - 93° 37’ W; 30° 37’ N - 93° 38’ W; 30° 23’ N - 93° 30’ W) (Figure 1). The locations had similar soil types and management histories. Soils at all three sites were very deep, poorly to somewhat poorly drained, silt loam Alfisols on nearly level to very gently sloping terraces of mid-to-late-Pleistocene age. These soils had a Bt (restrictive argillic) horizon, and the depth to this horizon was between 15-50 cm. The surface and subsoil textures were silt loam and silt clay loam, respectively. Soils at all three locations were considered within the Caddo-Messer complex (APPENDIX 1).

Figure 1. Study sites in southwestern Louisiana; Site I on Bailey Road, Site II on Jack Bennette Road, and Site III on Persimmon Road.

Site I at Bailey Road and Site II at Jack Bennette Road were flat and poorly drained (with a perched water table), whereas Site III at Persimmon Road was located on a broad ridge thus having a greater surface drainage, although it was somewhat poorly drained internally. A perched water table refers to a water table standing above an impermeable unsaturated zone above the normal water table. The climate at the sites is warm and humid with an average winter temperature of 11 °C and average summer temperature of 28 °C. Total annual precipitation averages 148 cm and is well distributed throughout the year (recorded from 1971-2000 at the DeQuincy weather station, LA). Site I at Bailey Road was planted with slash pine in 1961, and was clear-cut and mechanically bedded in May 2000 for this study. Site II at Jack Bennette Road was planted with slash pine in 1994 but was destroyed by wildfire in 1999. The site was bush-hogged and mechanically bedded in May 2000. Site III at Persimmon Road was planted with slash pine in 1963. It was clear-cut in March 2000 and mechanically bedded in June 2000.

Planting Stock

Planting stock tested in this study was slash pine bare-root seedlings (BRS) and containerized rooted cuttings (CRC). The BRS were produced through standard nursery culture at the Beauregard Nursery near Merryville, LA. The slash pine seeds were sown in mid- to late April. Nursery beds consisted of eight rows, 16.5 cm in width. Seedlings went through lateral and horizontal root pruning to ensure more compact, fibrous root systems. They were also top pruned to 23 cm to increase seedling uniformity and root:shoot ratio. The CRC were produced by Boise Corporation at their seed orchard near Evans, LA. Cuttings were harvested from less than three-year-old full-sib slash pine hedges. Two main crops were taken from the same hedges in April and June throughout the study period. Cuttings were rooted in 12.5-cm deep, 220 cm^3 containers at a density of 277/m^2. Growing media consisted of 40% perlite and 60% peat by volume. The first crop was used for September and November plantings, and the second crop was used for January, March and April plantings. CRC were full-sib and BRS were half-sib in the 2000-2001 and 2002-2003 planting season. They had one parent in common, whereas both CRC and BRS were full-sib from the same family in the 2001-2002 planting season.

Study Establishment

Both CRC and BRS were hand planted using standard techniques (Wakeley 1954, Balmer and Williston 1974, Lantz 1996) at the same time as suggested by Owston and Stein (1974). Within-row spacing was 1.80 meters; between-row spacing was approximately 3.35 meters or standard between-row spacing as determined by the bedding machinery. Dibble bars were used as planting tools. Special effort was made to keep the same planting crew throughout the study. Bare-root seedlings were lifted and planted on the same day except in April 2003, which used seedlings lifted in March 2003, and kept refrigerated until planting. Containerized rooted cuttings were also transported and planted on the same day.

Experimental Design and Plot Layouts

A split-plot design was used with planting date as the main plot and stock type as the sub-plot. Site I and Site III were planted on five dates (September, November, January, early March, late April) in three planting seasons (2000-2001, 2001-2002, and 2002-2003) with each season in a separate block. Site II was planted on the same dates as other sites in the 2000-2001 and 2001-2002 seasons, however it was planted only in September and November of the 2002-2003 season and abandoned later due to chronic flooding. Each season (block) contained ten replications of each month (plot). Each plot contained two row plots, one with BRS and the other with CRC. Each row contained 20 trees, with the first 15 trees reserved for growth and survival measurements, and the last five trees used for destructive biomass allocation measurements. Plots were randomly assigned within blocks and blocks were surrounded by planted buffer areas. This layout required the planting of 16,800 experimental trees: 20 tree-rows x two stock types x 10 replications x five planting dates (Site II was planted only on two planting dates in the third year) x three years x three locations.

Fertilization

All trees were fertilized at planting with diammonium phosphate (DAP) at the equivalent of 225 kg/ha. Fertilizer was hand-applied to the soil surface on the planting beds.

Chemical Vegetation Control

Prior to planting, sites were aerially sprayed with triclopyr and glyphosate to control competing vegetation. After planting, hexazinone and sulfometuron methyl was applied with backpack sprayers to control herbaceous vegetation and to promote uniformity across sites. No pest control was imposed.

Data Collection

Survival, height, root collar diameter, groundline diameter, diameter at breast height

Basic measurements included survival, height, root collar diameter (RCD), groundline diameter (GLD), and diameter at breast height (DBH; 1.37 m above groundline). Root collar diameter refers to diameter at naturally developed original root:shoot interface on the nursery beds or in the container. Groundline diameter refers to diameter at the soil surface after planting. Root collar diameter of 120 BRS was measured on the nursery bed before lifting. Groundline diameter of 120 CRC was also measured before planting. In addition, a subsample of each stock type was measured for groundline diameter to the nearest 0.5 cm just after planting; as expected, variation was too minimal to justify measuring all trees. These diameters served as initial diameters for each planting date - year combination. Initial height was measured to the nearest centimeter of 120 trees for each stock type before planting and for all trees soon after planting. Tree size (height, groundline diameter and diameter at breast height) of 2000-2001 plantings was measured again in January 2002, January

2003 and September 2003 to better identify early growth patterns. Diameter at breast height was measured for those trees that had a DBH of at least 1.5 cm. Height and groundline diameter measurements were also made in January 2003 for the trees planted in the 2001-2002 season.

Meteorological data

Meteorological instruments and CR10X dataloggers (Campbell Scientific Inc., Logan, UT, USA) were installed on each site for continual collection of environmental data. Rainfall was recorded with a tipping bucket rain gauge on each site. Air temperature and relative humidity were measured only on Site II, located in between the two other sites.

Soil moisture

Volumetric soil moisture content (soil surface to 15 cm deep) was determined using time domain reflectometry (TDR, Trase System, Soilmoisture Equipment Corp., CA, USA) on all sites at planting to investigate the relationship between survival and soil moisture content at planting.

Data Analysis

Analysis of variance (ANOVA) was performed using the General Linear Models procedure of SAS (SAS Institute 1997). Percentage survival data were arcsine transformed (Sokal and Rohlf 1969) before analysis, but untransformed means are presented for clarity. Mean separations were tested using Duncan's new multiple range test (α=0.05). Regression analyses were used to test the relationship between survival and soil moisture at the time of planting, and between survival and rainfall received fifteen days prior to and after planting. Unless otherwise noted, all references to statistical significance in this dissertation refer to the $\alpha = 0.05$ level.

Results

Survival

Both stock type and planting date affected first-year survival. Mean CRC survival across planting dates and the three sites was significantly ($P<0.0001$) higher than that of BRS for three consecutive planting seasons between September 2000 and April 2003. Survival of both stock types, particularly BRS, differed among the three planting seasons. Therefore, three seasons are shown separately.

2000-2001 planting season

Survival of CRC (96%) was significantly ($P<0.0001$) higher than that for BRS (81%) across all planting dates and locations for the trees planted in the 2000-2001 season. Mean BRS survival for the three sites varied from 90% for the April 2001 planting, to as low as 67% for March 2001 (Figure 2). However, mean CRC survival varied from 99% for the November 2000 and March 2001 plantings to 89% for April 2001. The coefficient of variation (CV) for BRS averaged around 22%, whereas it was 5% for CRC across all sites and planting dates.

First-year survival of BRS planted on Site II (75%) was significantly lower than that on Site I (84%) and Site III (84%) across planting dates. CRC survival across planting dates was significantly higher on Site III (98%) than on Site I (95%). Survival of CRC on Site II averaged 96% and did not differ significantly from that on either Site I or Site III across planting dates. There was a significant site x planting date interaction for BRS planted in the 2000-2001 season.

Survival on Site III (91%) was significantly higher than that Site II (86%) across planting dates and stock types. Survival on Site I (90%) did not differ from that on either Site III or Site II. Averaged across stock types and sites, the January 2001 planting gave the highest mean survival (94%), significantly higher than

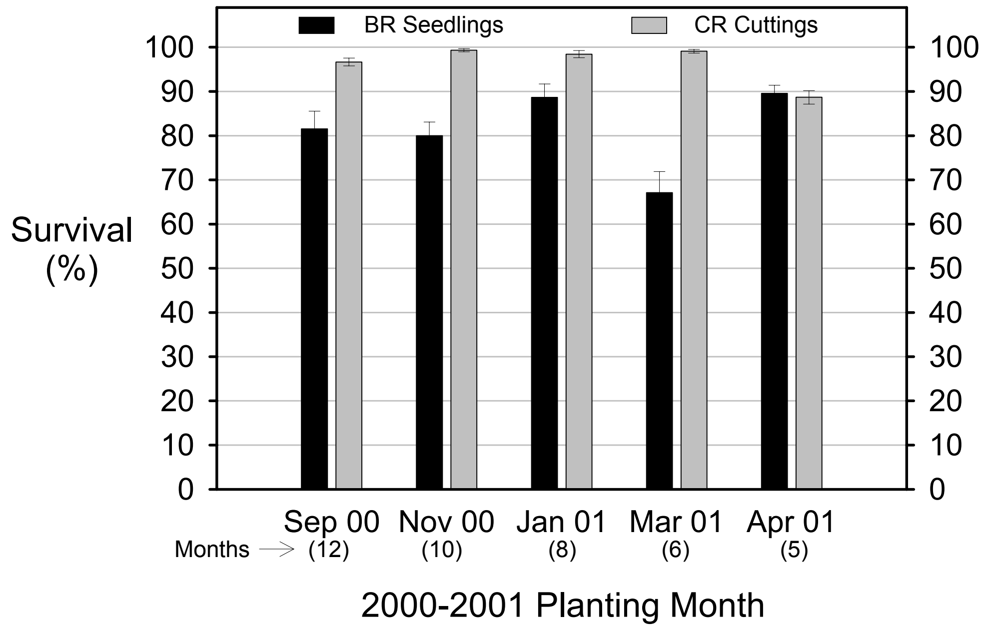


Figure 2. First-year survival of bare-root seedlings and containerized rooted cuttings of slash pine planted on five different dates between September 2000 and April 2001 in southwestern Louisiana. Average survival across three sites is shown. Survival was determined in September 2001. Error bars indicate one standard error. Numbers in parentheses show months since planting.

those of planted in other dates) whereas March 2001 gave the least (83%). The November 2000 plantings had significantly higher survival than did the March 2001 plantings. There was no significant difference in survival among the September 2000, November 2000 and April 2001 plantings across all sites and stock types.

2001-2002 planting season

Overall CRC first-year survival was significantly (P<0.0001) higher than that for BRS across all planting dates and locations for the trees planted in the 2001-2002 season (Figure 3). CRC survival averaged 98% while BRS survival was 77%. Mean BRS survival across sites varied from 95% for the November 2001 planting to as low as 52% for September 2001. CRC survival was 99% for September 2001, November 2001 and January 2002 plantings. The April 2002 planting had the lowest mean CRC survival with 96% across sites. The CV for

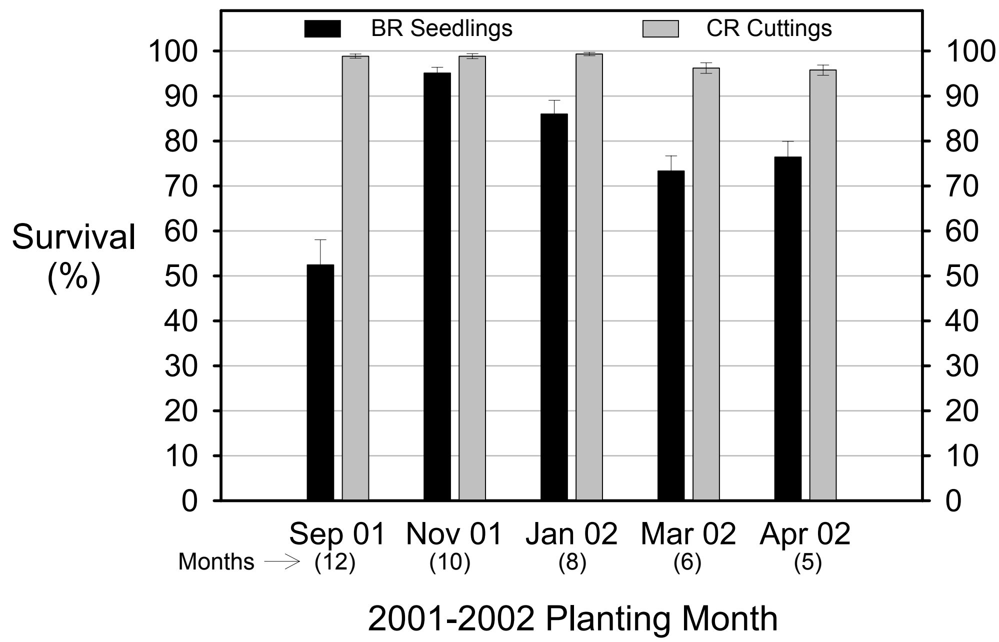


Figure 3. First-year survival of bare-root seedlings and containerized rooted cuttings of slash pine planted on five different dates between September 2001 and April 2002 in southwestern Louisiana. Average survival across three sites is shown. Survival was determined in September 2002. Error bars indicate one standard error. Numbers in parentheses show months since planting.

BRS averaged around 21%, whereas it was 5% for CRC across all sites and planting dates. Average survival for CRC did not vary significantly among sites. However, BRS survival was significantly higher on Site III and Site II than on Site I. Also, there was a significant site x planting date interaction for BRS planted in the 2001-2002 season. Averaged across stock types and sites, the November 2001 planting gave the highest mean survival (97%) whereas the September 2001 planting gave the least (76%). November 2001 and January 2002 plantings had significantly higher survival than did September 2001, March 2002 and April 2002 plantings. There was no significant difference between November 2001 and January 2002 or between April 2002 and March 2002 plantings across all sites and stock types. Site I had significantly lower survival than did Site II and Site III across planting dates and stock types. Survival on the Site II did not differ from that on Site III.

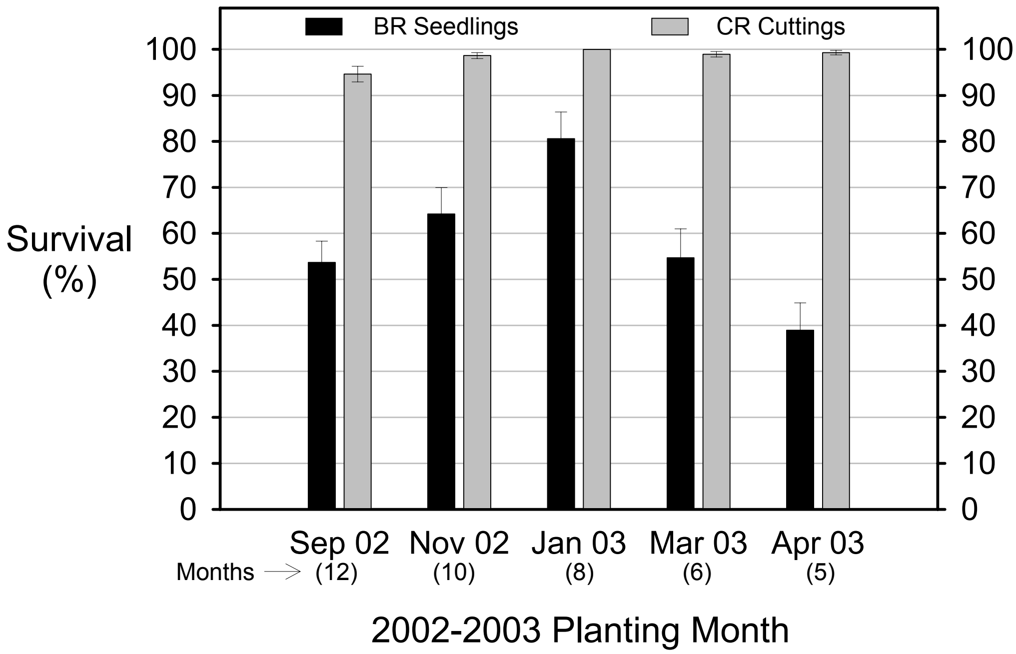


Figure 4. First-year survival of bare-root seedlings and containerized rooted cuttings of slash pine planted on five different dates between September 2002 and April 2003 in southwestern Louisiana. Average survival across three sites is shown. Survival was determined in September 2003. Error bars indicate one standard error. Numbers in parentheses show months since planting.

2002-2003 planting season

Again, CRC first-year survival was significantly (*P*<0.0001) higher than that for BRS across all planting dates and locations for the trees planted in the 2002-2003 season (Figure 4). CRC survival averaged 98%, whereas BRS survival was 59%, the lowest mean survival observed in the three planting seasons across sites. Mean BRS survival across sites varied from 81% for the January 2003 planting to as low as 39% for April 2003. Bare-root seedlings planted in April 2003 on the driest site had only 19% survival, whereas CRC survival for the same site was 99% (Table 1). Containerized rooted cuttings survival varied from 99 to 100% for all planting months except September 2002, where it was 95%

Table 1. Average first-year survival of bare-root seedlings and containerized rooted cuttings established on three sites through three years. Survival was determined in the following September for each planting season when trees were 5 to 12 months in the ground. Numbers followed by same letters are not significantly (α=0.05) different within each group.

	SURVIVAL (%)							
	Bare-root seedlings				**Containerized rooted cuttings**			
Planting date	Site I	Site II	Site III	I+II+III	Site I	Site II	Site III	I+II+III
2000-2001				**81 b**				**96 a**
Sep-2000 $_{12}$*	97	64	84	82 bc	97	97	96	97 b
Nov-2000 $_{10}$*	89	75	76	80 c	99	99	99	99 a
Jan-2001 $_{8}$*	91	79	97	89 a	98	97	100	98 a
Mar-2001 $_{6}$*	53	70	78	67 d	98	99	100	99 a
Apr-2001 $_{5}$*	90	92	87	90 ba	85	89	93	89 c
2001-2002				**77 b**				**98 a**
Sep-2001$_{12}$*	23	58	76	52 d	97	99	100	99 a
Nov-2001$_{10}$*	97	96	92	95 a	99	98	99	99 a
Jan-2002 $_{8}$*	77	94	87	86 b	99	99	100	99 a
Mar-2002 $_{6}$*	67	73	80	73 c	95	95	99	96 b
Apr-2002 $_{5}$*	89	79	62	76 c	97	97	94	96 b
2002-2003				**59 b**				**98 a**
Sep-2002 $_{12}$*	50	39	72	54 c	96	89	99	95 b
Nov-2002 $_{10}$*	45	51	97	64 b	99	97	100	99 a
Jan-2003 $_{8}$*	64	†	97	81 a	100	-	100	100 a
Mar-2003 $_{6}$*	31	†	79	55 c	99	-	99	99 a
Apr-2003 $_{5}$*	59	†	19	39 d	99	-	99	99 a

* Time since planting. † Site was abandoned after November 2002 planting.

across sites. The CV data show that BRS performance was highly variable (CV=33%) compared to that of CRC (CV=5%) across all sites and planting dates. Average survival for CRC did not vary significantly among sites. However, BRS survival was significantly higher on Site III compared to Site I and Site II. Also, there was a significant site x planting date interaction for BRS planted in the 2002-2003 season. Averaged across stock types and sites, the January 2003 planting gave the highest mean survival (90%, and significantly higher than other months) whereas April 2003 planting gave the least (69%). November

2002 planting had significantly higher survival than did September 2002 and April 2003. Survival of March 2003 planting did not differ significantly from November 2002 and April 2003 plantings.

Soil moisture at the time of planting

Volumetric soil moisture, measured on the beds March 2001 through April 2003 at the time of planting, generally increased September through March and decreased March through April. Since Site III was on a broad ridge and had better surface drainage, the average soil moisture on this site was lower than that of Site I and Site II (APPENDIX 2). Regression analyses were used to examine the relationship between first-year survival and soil moisture at the time of planting. This relationship was significant in ten out of thirteen plantings for BRS across all sites. However CRC survival was not significantly affected by variation in soil moisture except in the September 2001 plantings where first-year survival and soil moisture at the time of planting had a negative relationship across all sites (APPENDIX 3). September through March BRS survival was generally negatively correlated with soil moisture, whereas for April plantings in the 2001-2002 and 2002-2003 seasons, the opposite was observed (Figure 5).

The highest correlation between soil moisture content at time of planting and first-year survival was found for BRS planted in April 2002 on Site III, the site with the greatest drainage. Bare-root seedlings survival there was positively correlated (r^2=0.86, P<0.0001) with soil moisture at the time of planting, whereas CRC survival was not significantly (P=0.14) related to soil moisture on the same site and planting date (Figure 6).

When data for all planting dates and sites were combined, there were no significant relationship between volumetric soil moisture content at the time of planting and first-year survival of either BRS and CRC planted in the 2001-2002

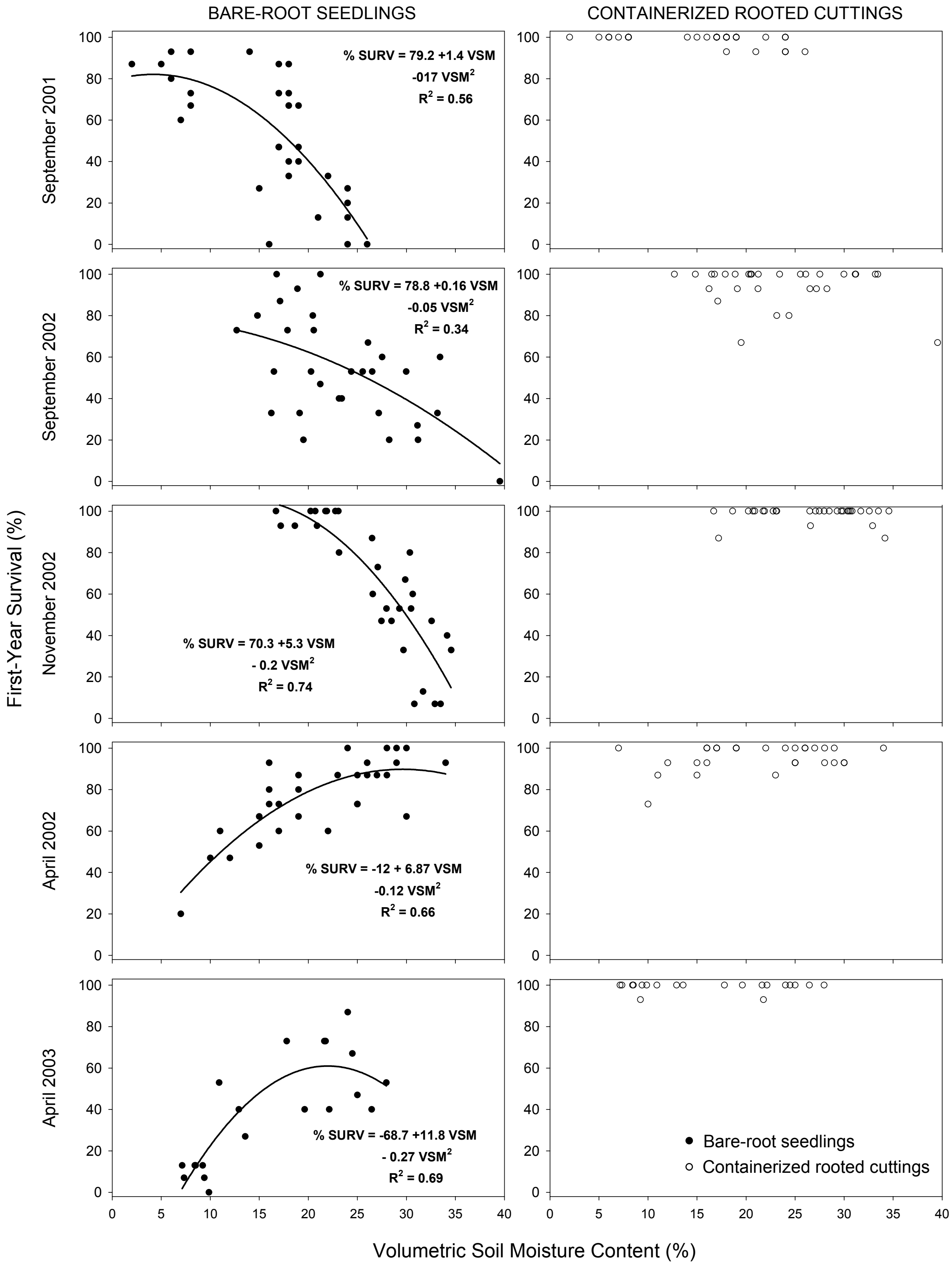


Figure 5. Relationship between volumetric soil moisture at the time of planting and first-year survival of bare-root seedlings and containerized rooted cuttings of slash pine planted on different dates on three sites in southwestern Louisiana. All fits were significant at P<0.05 level.

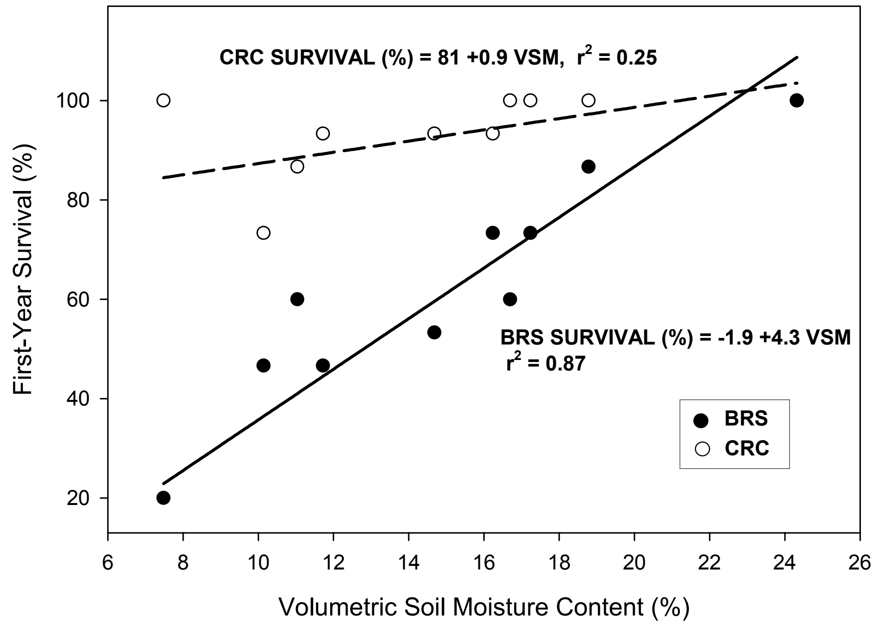


Figure 6. Relationship between volumetric soil moisture (VSM) content at the time of planting and first-year survival of bare-root seedlings and containerized rooted cuttings planted in April 2002 on a drier site (Site III) in southwestern Louisiana.

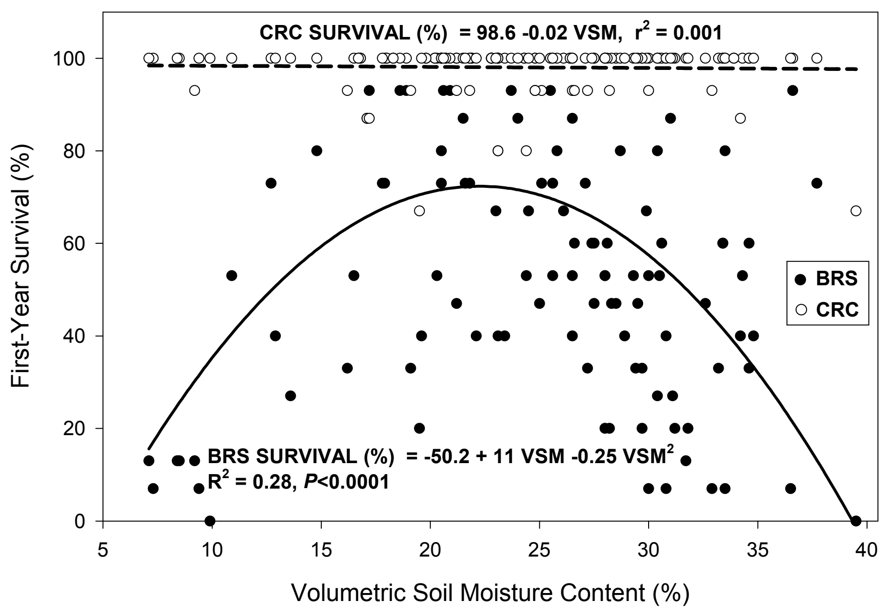


Figure 7. Volumetric soil moisture content at the time of planting and first-year survival of bare-root seedlings and containerized rooted cuttings planted in the 2002-2003 season in southwestern Louisiana. First-year survival of CRC did not significantly relate to soil moisture content at the time of planting.

season or CRC planted in the 2002-2003 season. However, there was a significant ($P<0.0001$) relationship between BRS first-year survival and volumetric soil moisture content at the time of planting in the 2002-2003 planting season (Figure 7). Twenty-eight percent of the variation in BRS first-year survival could be explained by volumetric soil moisture at the time of planting.

Initial Morphological Characteristics

Initial size of both stock types (height, root collar diameters (RCD), dry root and top weights) were determined at the time of planting for the 2001-2002 and 2002-2003 seasons. Heights of BRS were greater than those of CRC for all plantings except April 2003, when CRC were taller. Although post-planting heights of both stock types were lower than pre-planting heights, indicating that trees were planted deeper than the original root:shoot interface, BRS height difference between pre- and post-planting was greater compared to that of CRC (Table 2). In other words, BRS was planted deeper than CRC. Height and root collar diameters of BRS were generally higher when planting was delayed from September to April. Bare-root seedlings had greater root collar diameters than did CRC, except in September 2002 and September 2003. Bare-root seedlings` RCD were 4 mm or thicker in all planting months except in the September 2002 planting. However, CRC RCD were lower than 4 mm in September 2002 through January 2003. The RCD differences between stock types increased from September to April for the 2002-2003 planting season. Bare-root seedlings` root dry weights were comparable to those of CRC with the exception of the September and November 2002 plantings when CRC root dry weight was significantly greater (Table 3). However, BRS generally had greater top dry weights compared to CRC. Consequently, CRC had significantly higher root:shoot ratios than did BRS for all months except January 2003.

Height, Groundline Diameter (GLD) and Diameter at Breast Height (DBH)

Both planting date and stock type significantly affected aspects of tree size at

Table 2. Initial morphological characteristics of slash pine seedlings and containerized rooted cuttings at the time of planting. Only 2001-2002 and 2002-2003 plantings were measured. Numbers followed by same letters are not significantly (α=0.05) different within each group according to Duncan's new multiple range test.

Planting Date	Bare-root seedlings			Containerized rooted cuttings		
	Pre-planting		Post-planting	Pre-planting		Post-planting
	RCD(mm)	Height(mm)	Height (mm)	RCD (mm)	Height (mm)	Height (mm)
			2001-2002			
Sep-01	4.0 c	265 b	165 d	4.1 c	225 a	190 a
Nov-01	5.1 b	230 d	180 b	4.1 c	195 b	180 b
Jan-02	5.5 a	250 c	160 d	4.4 b	215 a	175 b
Mar-02	5.7 a	260 b	175 c	4.5 b	195 b	145 d
Apr-02	5.2 b	365 a	295 a	4.8 a	220 a	170 c
Mean	5.1	275	195	4.4	210	175
			2002-2003			
Sep-02	3.3 e	195 c	115 d	3.6 b	170 dc	140 d
Nov-02	4.6 d	235 b	145 c	3.7 b	165 d	155 b
Jan-03	5.0 c	260 a	145 c	3.6 b	180 c	135 d
Mar-03	5.9 b	265 a	170 a	4.5 a	210 b	150 c
Apr-03	6.2 a	260 a	160 b	4.6 a	330 a	260 a
Mean	5.1	245	145	4.0	210	165

Table 3. Initial component dry weights and root:shoot ratios of slash pine seedlings and containerized rooted cuttings before outplanting. Only 2001-2002 and 2002-2003 plantings were measured. Numbers in parentheses are standard errors. Means followed by "*" are significantly (α = 0.05) greater compared to other stock type for each planting date separately.

Planting Date	Bare-root seedlings			Containerized rooted cuttings		
	Dry weight (g)		Root:shoot ratio	Dry weight (g)		Root:shoot ratio
	root	top		root	top	
			2001-2002			
Sep-2001	0.60(0.05)	2.29(0.19)	0.27(0.02)	0.77(0.11)	1.77(0.19)	0.43(0.04)*
Nov-2001	1.06(0.09)	3.67(0.28)*	0.29(0.02)	1.06(0.12)	2.13(0.17)	0.49(0.04)*
Jan-2002	1.36(0.20)	4.38(0.61)*	0.31(0.01)	1.55(0.17)	2.78(0.21)	0.56(0.04)*
Mar-2002	1.23(0.09)	3.73(0.26)*	0.33(0.01)	1.42(0.11)	2.14(0.16)	0.66(0.02)*
Apr-2002	1.10(0.07)	3.91(0.22)	0.28(0.01)	1.14(0.11)	3.03(0.22)	0.38(0.02)*
Mean	1.07	3.60	0.30	1.19	2.37	0.50
			2002-2003			
Sept-2002	0.42(0.04)	1.94(0.17)	0.23(0.01)	0.60(0.04)*	1.64(0.07)	0.36(0.01)*
Nov-2002	0.57(0.03)	2.69(0.16)*	0.21(0.01)	0.87(0.09)*	1.79(0.11)	0.48(0.03)*
Jan-2003	1.00(0.08)	2.72(0.23)	0.37(0.01)	1.22(0.09)	3.09(0.20)	0.40(0.02)
Mar-2003	1.41(0.12)	5.68(0.39)*	0.25(0.01)	1.22(0.07)	2.89(0.11)	0.42(0.02)*
Apr-2003	1.23(0.11)	3.72(0.27)	0.33(0.01)	1.36(0.07)	3.30(0.12)	0.41(0.01)*
Mean	0.93	3.35	0.28	1.05	2.54	0.41

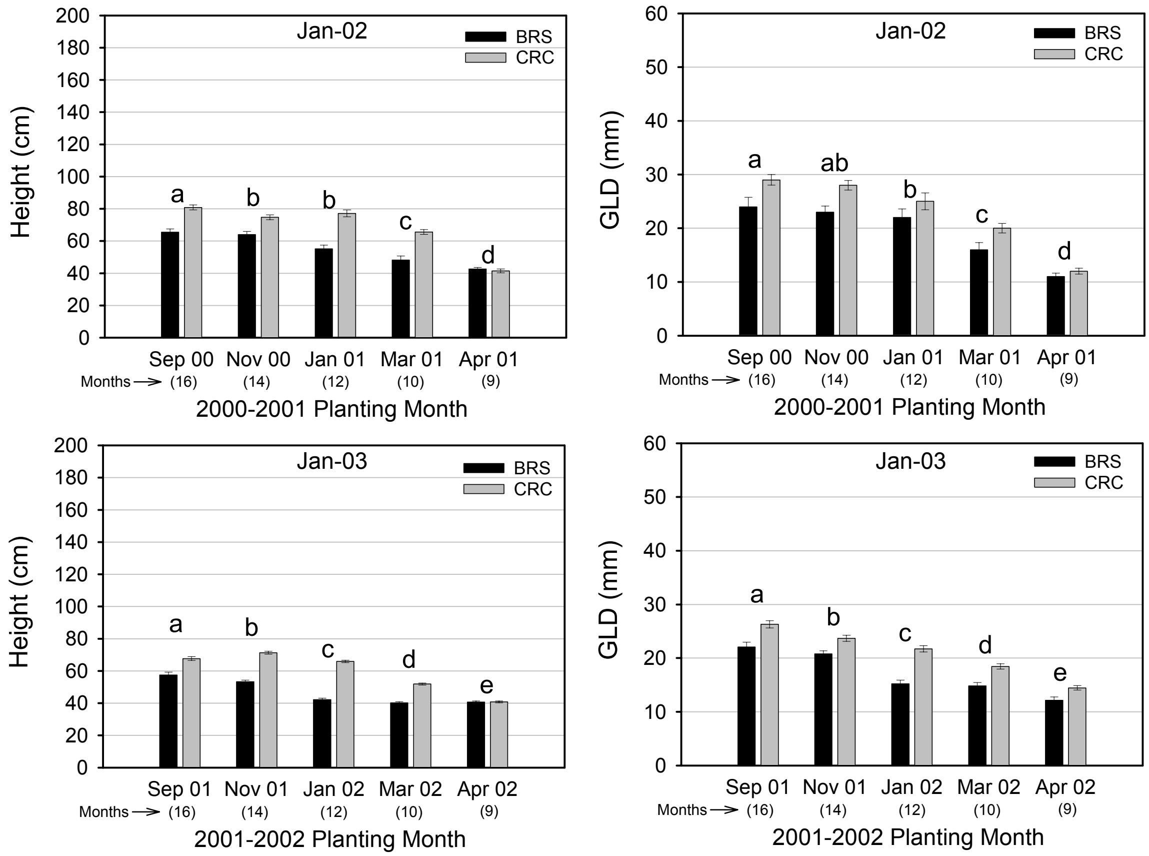


Figure 8. Mean height and groundline diameters (GLD) of slash pine bare-root seedlings and containerized rooted cuttings established in the 2000-2001 and 2001-2002 planting seasons. Error bars indicate one standard error. Trees were measured in January 2002 (top) and January 2003 (Bottom). Numbers in parentheses show months since planting. Letters are statistical differences (α=0.05) for months as a main effect.

the end of the first and second growing seasons. Generally, the longer the trees were in the ground, the larger they were. First-year height and groundline diameter (GLD) growth trends were similar in the 2000-2001 and 2001-2002 planting seasons. CRC planted in both 2000-2001 and 2001-2002 were significantly taller after approximately one year than BRS in every planting month, except for April, when there was no difference. Likewise, CRC planted in both 2000-2001 and 2001-2002 were significantly thicker at groundline than BRS in every planting month, except for January and April 2001 when there was no difference (Figure 8). There was a significant site effect on height growth

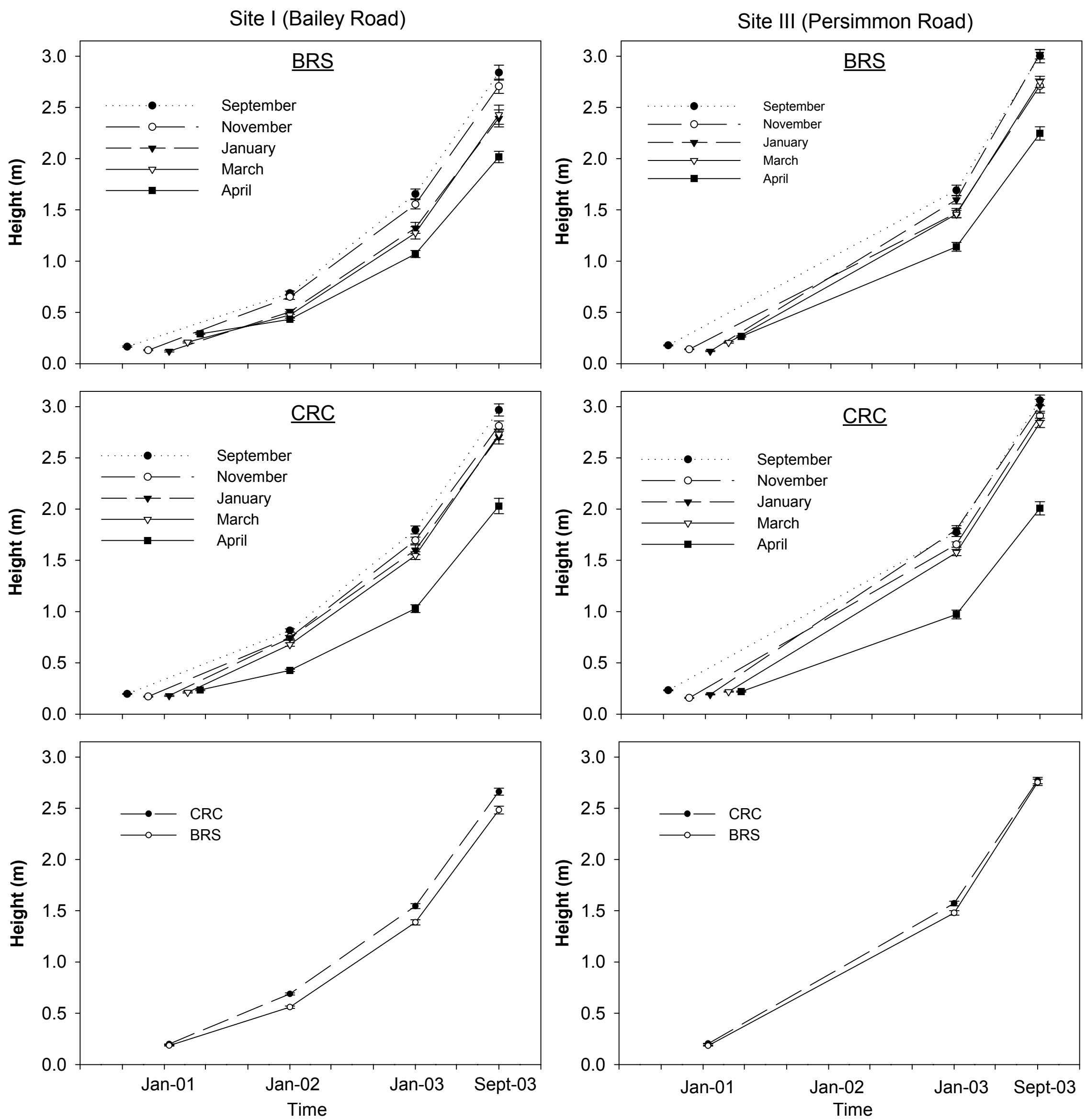


Figure 9. Mean height growth of slash pine trees established as bare-root seedlings (BRS) and containerized rooted cuttings (CRC) between September 2000 and April 2001 on two sites in southwestern Louisiana. Points represent mean height of each stock type across five planting dates on the bottom row. Error bars indicate one standard error.

three years after planting. Differences in height growth that developed early in the study were maintained through time on Site I, whereas height differences between BRS and CRC across planting dates disappeared three years after planting on Site III (Figure 9). Among BRS planted in different months on Site I, September trees were tallest (2.84 m), but not much taller than November trees (2.71 m) after three years. January and March trees differed very little (2%) from each other, but were consistently shorter (10-16%) than September and November trees. April trees were substantially shorter (15-29%) than those in any other month.

On Site III, BRS planted in September and January differed very little (1%) from each other but were consistently taller (8-25%) than those planted in any other month. November and March trees also performed comparably (difference as small as 1%), but were shorter (8-10%) than September and November trees. Bare-root seedlings planted in April were again substantially shorter (17-25%) than those planted in any other month on this site.

After three years, on both sites, CRC planted in September were the tallest among trees planted on different dates, with mean heights of 2.97 m and 3.06 m on Site I and Site III, respectively. Heights of CRC planted November through March trees varied little (1-4%) on Site I. Height difference between September and March was as much as 6% for Site III. As with BRS, CRC planted in April were considerably shorter (25-34%) than trees from those in other months on these sites. Furthermore, height differences between April and the other months appeared to be increasing through time.

The direct relationship between time in the ground and tree size also held for GLD for the second year (Figure 10). Trees planted earlier had higher GLDs. However early GLD differences between BRS and CRC disappeared at the end of the second growing season for both sites. Again, measurements in the third year showed that there was no significant GLD difference between BRS and CRC across different planting months for both sites. Groundline diameter averaged 6.5 cm for CRC and was slightly greater (2%) than that of BRS across

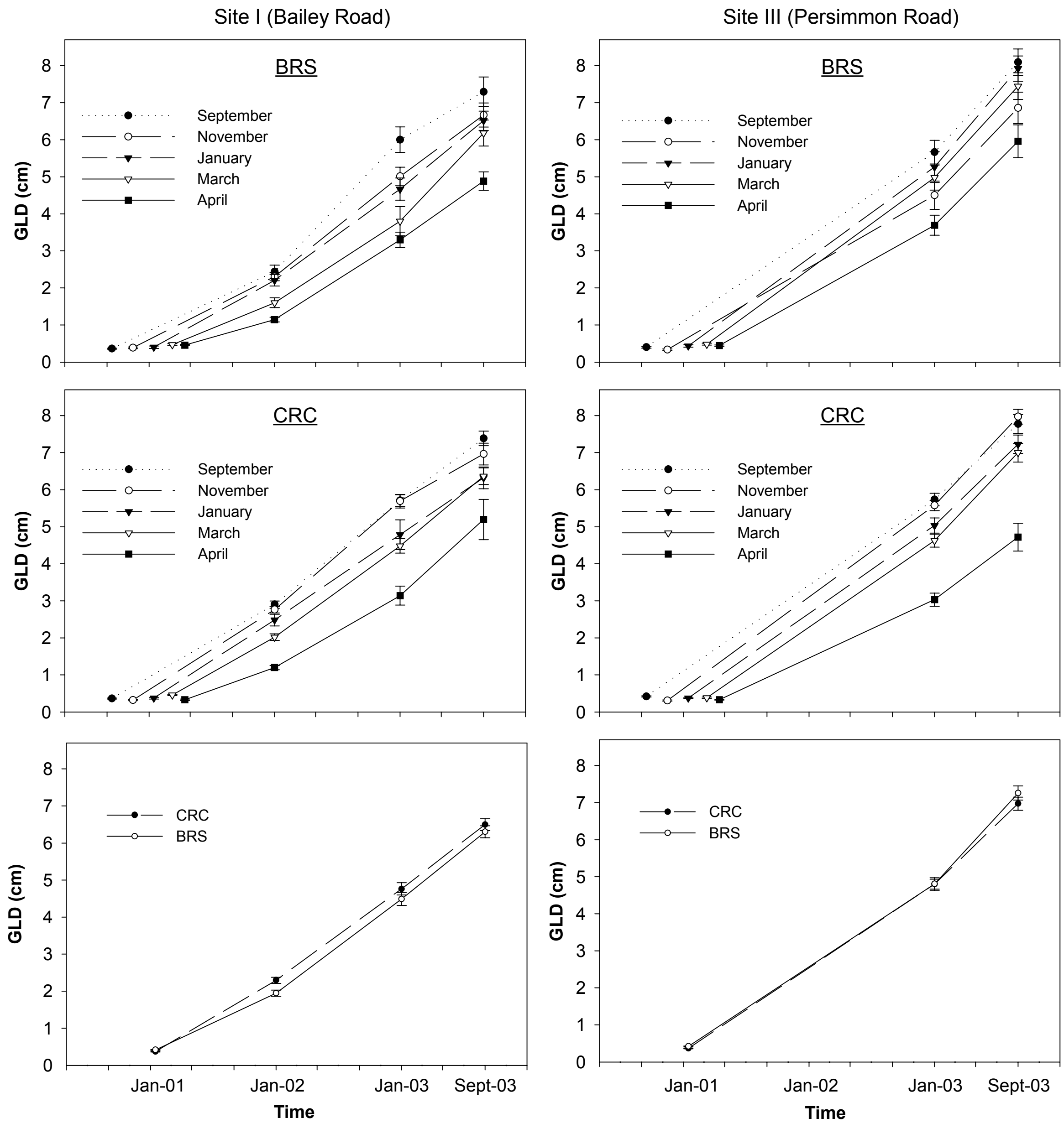


Figure 10. Mean groundline diameter growth of slash pine trees established as bare-root seedlings and containerized rooted cuttings between September 2000 and April 2001 on two sites in southwestern Louisiana. Points represents mean groundline diameter across five planting dates for each stock type on the bottom row. Error bars indicate one standard error.

planting dates on Site I. Mean GLD of BRS was 7.3 cm, only 4% greater than that of CRC on Site III. After three years, September-planted trees continued to be thickest at groundline among those planted on both sites except for CRC on Site III where November-planted trees were slightly thicker (3%). Alternatively, April-planted trees had the lowest GLD among trees planted on these sites. However GLD differences among trees planted September through March lessened during the third year.

Diameter at breast height was first measured at the end of the second growing season for those trees planted in 2000-2001 that had a DBH of at least 1.5 cm. This first measurement showed that DBH did not differ significantly between stock types or among planting dates after two years (Figure 11). As expected, early plantings had a larger percentage of trees that had developed a DBH (at least 1.5 cm) than did the later plantings (Figure 11).

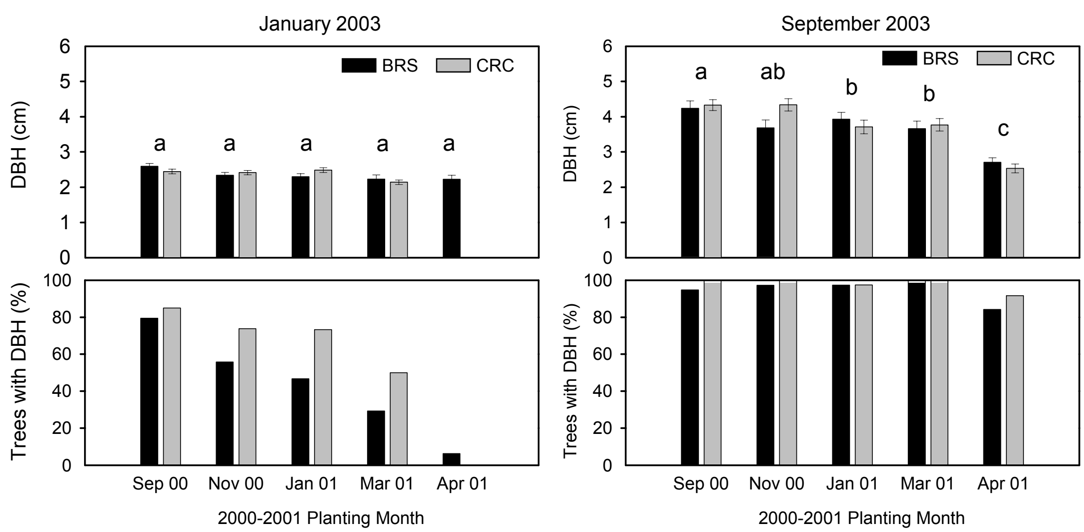


Figure 11. Top: Mean diameter at breast height of 2000-2001 plantings measured in January and September 2003. Error bars indicate one standard error. Letters are statistical differences (α=0.05) for months as a main effect. Bottom: Percentage of trees that had developed DBH of at least 1.5 cm on these measurement dates.

Table 4. Third-year height, GLD and DBH of trees planted in different months in the 2000-2001 planting season on Site I and Site III. Numbers in parentheses are standard errors. Main effects within groups followed by the same letter are not significantly different (α = 0.05) according to Duncan's new multiple range test.

Planting date	Height (m)		GLD (cm)		DBH (cm)	
	BRS	CRC	BRS	CRC	BRS	CRC
			Site I (Bailey Road Site)			
September $_{36}$*	2.84(0.07)a	2.97(0.06)a	7.3(0.40)a	7.4(0.20)a	4.0(0.30)a	4.2(0.21)a
November $_{34}$*	2.71(0.07)a	2.81(0.05)b	6.7(0.33)ab	7.0(0.29)ab	3.5(0.26)ab	4.0(0.21)ab
January $_{32}$*	2.39(0.08)b	2.71(0.07)b	6.5(0.26)ab	6.3(0.30)b	3.4(0.20)ab	3.5(0.24)b
March $_{30}$*	2.43(0.09)b	2.73(0.05)b	6.2(0.35)b	6.4(0.22)b	3.1(0.24)bc	3.7(0.23)ab
April $_{29}$*	2.02(0.06)c	2.03(0.07)c	4.9(0.25)c	5.2(0.54)c	2.5(0.16)c	2.5(0.15)c
	2.48 (0.04) b	2.66 (0.03) a	6.32 (0.2) a	6.46 (0.2) a	3.30 (0.1) b	3.58 (0.1) a
			Site III (Persimmon Road Site)			
September $_{36}$*	3.00(0.07)a	3.06(0.05)a	8.1(0.36)a	7.8(0.25)a	4.5(0.25)a	4.5(0.22)ab
November $_{34}$*	2.71(0.07)b	2.91(0.04)bc	6.9(0.43)bc	8.0(0.2)a	3.9(0.36)a	4.9(0.24)a
January $_{32}$*	3.02(0.05)a	3.00(0.07)ab	7.9(0.34)ab	7.2(0.25)ab	4.6(0.31)a	4.1(0.31)b
March $_{30}$*	2.75(0.05)b	2.84(0.05)c	7.4(0.36)ab	7.0(0.25)b	4.4(0.32)a	3.8(0.28)b
April $_{29}$*	2.25(0.07)c	2.01(0.06)d	6.0(0.44)c	4.7(0.38)c	3.0(0.20)b	2.5(0.22)c
	2.75(0.03) a	2.77(0.03) a	7.26(0.2) a	6.97(0.2) a	4.12(0.1) a	4.01(0.1) a
Site						
Site I $_{29\text{-}36}$*	2.58(0.03) b		6.40(0.1) b		3.49(0.1) b	
Site III $_{29\text{-}36}$*	2.76(0.02) a		7.11(0.1) a		4.06(0.1) a	

* Time since planting (months).

In the third year, DBH differences developed between stock types on Site I and among planting dates for both sites. On Site I, September trees had the largest DBH (4.1 cm) and April had the smallest (2.5 cm). November 2000 (3.8 cm) through March 2001 (3.4 cm) trees had intermediate DBHs that did not differ significantly from each other.

On Site III, BRS planted in January and CRC planted in November had the largest DBH (4.6 cm and 4.9 cm, respectively). However, both BRS and CRC planted in April had the lowest DBH on both sites (Table 4). CRC had significantly larger (8%) DBH than did BRS on Site I after three years, whereas CRC and BRS performed comparably (difference was only 3%) on Site III.

Height, GLD and DBH of trees planted on Site I and Site III did not differ significantly between sites at the end of the second growing season, but after three years, trees on Site III had significantly greater heights, GLDs and DBHs.

Total Plot Height

Height data for the 2000-2001 plantings were weighted with survival data by calculating a total plot height representing the sums of all existing trees on sub-sampled plots on Site I and Site III in September 2003 (Figure 12). CRC had higher total tree plot height than did BRS for all planting months except for April on both sites. Total plot height varied little September through March for CRC on these sites. For BRS, September planting on Site I and January plantings on Site III had the highest total plot heights, Bare-root seedlings planted in the spring (March and April) had the lowest total plot height on Site I, whereas plot heights of BRS planted in November were as low as spring planting on Site III.

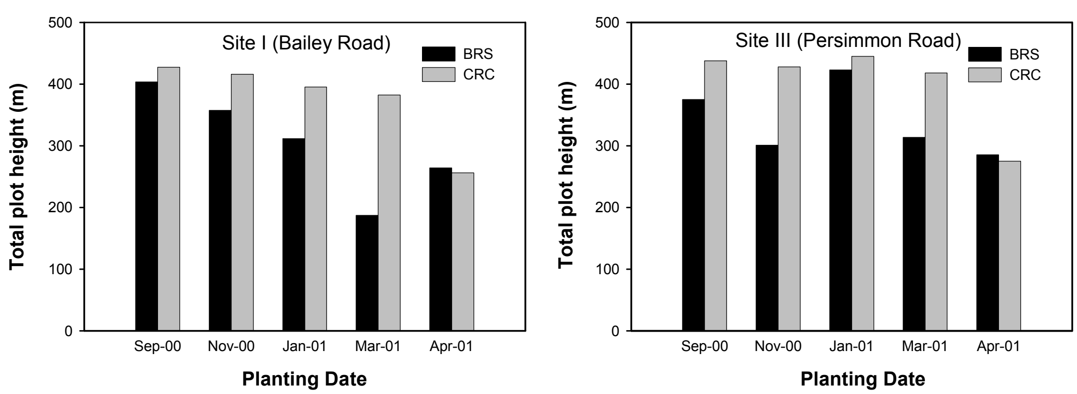


Figure 12. Total plot height of slash pine trees measured in September 2003. Trees established as bare-root seedlings and containerized rooted cuttings between September 2000 and April 2001 on two sites in southwestern Louisiana.

Precipitation Pattern and Distribution

Total monthly rainfall did not differ significantly among sites between September 2001 and May 2003, although some monthly deviations were observed (APPENDIX 4). Monthly rainfall patterns on study sites were generally comparable to those recorded by the DeQuincy weather station nearby.

There was no significant relationship between first-year survival and rainfall received on each site in the fifteen days preceding planting or the fifteen days following planting for the 2001-2002 and 2002-2003 seasons. Daily rainfall data were not available for the 2000-2001 season for each site.

Although year 2000 had 220 mm below-average rainfall, it had a rather wet fall season. September 2000 had near-average rainfall (120 mm). In the fourteen days preceding the September 2000 planting, 100 mm of the rain was received with 18 mm of it being received on planting day and the following day. Even though maximum air temperature was 28 °C (APPENDIX 5), which is almost critical for planting (Long 1991), heavy rain received around the September 2000 planting might have alleviated this critical situation and helped the bare-root seedlings to have 97% first-year survival on Site I. The study area received well above-average rainfall in November 2000. Standing water was present on the study sites between planting beds November 2000 through March 2001.

The year 2001 had about 430 mm above-average rainfall. March, June, and August through November received the surplus rain. April and May were drier months with below-average rainfall. However, the sites received some rain (7 mm) two days preceding the planting in April 2001. On September 22, 2001, air temperature was critical for planting (34.5 °C); yet again, the sites received rain on the planting day and the following two days after planting (57, 32, 20 mm, for Site I, Site II and Site III, respectively). Sites did not receive any rain for 26 consecutive days before the November 2001 planting, which made the Site III (the site with greater drainage) drier on the planting day compared to the other two sites. However, the end of November brought a substantial amount of rain (about 300 mm).

2002 also had a considerable amount of above-average annual rainfall (about 400 mm surplus). The surplus rain was received July through December, whereas the sites had below-average rainfall January through May. In April 2002, the sites received about 70 mm of rain ten days before planting. The air temperature was critical (29 °C) for planting but the relative humidity was over 50%. On Site I standing water was still present at lower points in April 2002 planting. Site III was the driest among the sites. Consequently survival was lower in Site III compared to the other two sites. Air temperature was critical (35°C) on the September 2002 planting day, but the sites received some (10-30 mm) rain during the preceding week and a considerable amount of rain (75-120 mm) in the following week. On Site I and Site II, standing water was present between the planting beds. Again Site III was the driest and did not have any standing water. October with 330 mm and December with 430 mm rainfall had the most of the surplus rain in 2002. This led the soil to be saturated on poorly drained sites from fall through the following early spring. We abandoned the second site on this point due to flooding.

2003 started with below-average rainfall in January but received about 230 mm rainfall in February which supplied surplus soil moisture for the early March planting (6 March 2003). The air temperature was critical (31 °C) and relative humidity was marginal (39%) for planting on the April planting day. Although the sites had some rain (10-18 mm) during the following week, March through May, rainfall received in the region was below average.

Discussion

Average first-year CRC survival across sites was always higher than 90%, except in April 2001 (89%), whereas BRS survival was as low as 39% in April 2003.

The coefficient of variation (CV) for CRC survival (5%) was much lower than that for BRS (21-33%) throughout the study. This high variation in BRS survival across planting dates and sites indicates that BRS was more susceptible to environmental stresses than CRC. High variation in BRS survival also might have been caused by the damage suffered by BRS during lifting, transportation, and planting.

The greater survival of CRC over BRS averaged as much as 40% in the 2002-2003 planting season at the end of the 2003 summer. Survival was lower for BRS planted September through March on the poorly drained sites compared to that of the somewhat poorly drained Site III after this planting season. This was possibly caused by water logging (thus inadequate soil aeration) due to above-average rainfall received in the fall of 2002. Seedlings planted early on poorly drained sites with a perched water table must tolerate long periods of excessive moisture in order to survive (Yeiser and Paschke 1987). Even though sites were bedded, elevation of the beds was highly variable, making some parts of the beds saturated due to ponding of excessive water. On silt loam soils where the depth to free water is less than 46 cm after winter rains, bedding increases slash pine performance by improving aeration and increasing drainage (Haywood et al. 1990). However, bedding can disrupt the natural drainage patterns and may cause water accumulation in depressions subsequently adversely affecting tree development on gently rolling silt loam soils (Haywood 1995).

An inverse relationship between BRS survival and soil moisture at the time of planting across sites during these months also suggests that BRS survival was adversely affected by water logging in some part of the year. Yet, high CRC survival indicates that CRC was not significantly affected by excessive water on the same sites. This results agrees with Yeiser and Paschke`s (1987) findings with containerized loblolly pine seedlings planted on a site with a perched water table. Perhaps soil compaction during planting might have adversely affected the air holding capacity of soils causing more mortality in BRS. However, intact growing media of CRC with its greater air holding capacity (due to porous material, i.e. perlite) and buffering roots against damage during planting might have been one of the major reasons of high survival and early growth of CRC. Also, BRS might have been more susceptible to anoxia since they were planted deeper compared to CRC.

Occasionally, BRS had high first-year survival rates in some early and late planting months (i.e., September 2000 planting on Site I, 97%). Even though maximum air temperatures were critical (or close to critical) (APPENDIX 5) for planting, rain received around planting dates and high relative humidity likely alleviated this critical situation and helped BRS survive outside of a “normal” planting season.

BRS lowest survival was always observed in early or late planting dates. Bare-root seedlings planted in March 2001 on Site I, had a 51% survival rate after two years. Likewise, second-year survival of BRS planted in September 2001 was only 23% on the same site. However, CRC survival was 93% and 97% respectively, for the same dates on this site. Survival results indicated that both early and late planting with BRS was not reliable, whereas CRC survival was less affected by planting date, suggesting that planting CRC possibly extends the traditional planting season. This is consistent with others findings with longleaf pine (*Pinus palustris* Mill.) (Goodwin 1976), red pine (*Pinus resinosa*) (Marion and Alm 1986), and loblolly pine seedlings (Goodwin 1976, Barnett and McGilvray 1993).

There was a strong positive relationship between soil moisture at the time of planting and first-year survival of BRS planted in April 2001 and April 2002. For CRC, the relationship was not significant. When average volumetric soil moisture was 10% at planting on Site III (the driest site) in April 2003, BRS had only 19% survival, whereas CRC survival for the same site was 99%. This high survival of CRC in low soil moistures might be due to their intact root systems protected by the container media, which enables them to go through a shorter period of planting shock. This agrees with other studies with bigtooth aspen (*Populus tremuloides*) (Okafo and Hanover 1978), slash pine (Anderson et al. 1984) loblolly pine (South and Barnett 1986), ponderosa pine (*Pinus ponderosa*) (Sloan et al. 1987) and longleaf pine seedlings (Boyer 1988).

CRC planted between September 2000 and March 2001 had greater height and GLD growth compared to BRS in January 2002 (10 to 16 months after planting). Measurements in January 2003 showed that 21 to 28 months after planting, CRC were taller than BRS. However, the GLD difference between stock types was negligible in the second year. This might further suggest that the greater height and GLD increment of CRC in the first growing season is an indication of that stock's quick adaptation to its environment after being planted; whereas second- and third-year growth of BRS was comparable to that of CRC. The often much lower survival of BRS makes total area-wide production less than that of CRC. Other research demonstrated the higher survival of cuttings compared to seedlings (Stelzer et al. 1998, Frampton et al. 2002).

Generally speaking, the longer the trees were in the ground, the larger their size at the end of the first and second growing seasons for both Site I and Site II. This trend held for poorly drained Site I after the third summer from planting. However on the better-drained Site III, relationship between tree size and the time in the ground was less evident, except for trees planted in April, which were substantially smaller compared to those planted in other months. This indicates that planting both BRS and CRC earlier holds more promise than later planting in terms of early growth. Dierauf (1976) reported that loblolly pine bare-root seedlings planted earlier (mid-October) in Virginia were the first to begin height growth the following spring and were the tallest after three seasons among those planted from October to March.

Height differences between stock types started to lessen in the second growing season. Bare-root seedlings` height increment averaged across all five planting dates was greater in the second growing season than that of CRC, but CRC had greater height increment in the first year. Foster et al. (1987) found that rooted cuttings were significantly taller at ages one and four although the seedlings had higher relative growth rates. These results indicate that the differences in early years might diminish as the trees mature. Stelzer and others (1998) did not find any differences in height, DBH, volume or stem taper between rooted cuttings and seedlings of loblolly pine ten years of age, although they reported early age differences.

Three years later, CRC planted in March 2001 were comparable to those planted in November 2000, in terms of both size and survival, demonstrating that the planting season can be extended as late as March with CRC. However, survival data show that March planting of BRS should be avoided. CRC provided a wider planting window in that height growth varied little among September, November, January, and March plantings, suggesting that trees can be planted anytime between September and March, with reasonably good results.

However, even with CRC, April planting should be avoided since April trees had the lowest growth among planting months. Although some trees planted in April had comparable growth to those planted in March and January, there was a large variation within April rows. April planting resulted in numerous stunted trees, even into their third growing season (Figure 13). Growth differences between April plantings and other planting months increased annually. South and Barnett (1986) found that three years after planting, March-planted loblolly pine seedlings were 16% taller and had 26% greater DBH than May-planted seedlings. They suggested that late planting should be avoided because of growth reductions. In another study with loblolly pine, May planting resulted in less growth for both container and bare-root stock compared to March and April planting (Barnett and McGilvray 1993).

Third-year growth data indicate that growth was lower on the poorly drained Site I compared to Site III where drainage was greater. Anaerobic conditions significantly reduce root development (Schultz 1997) and tree height growth is strongly correlated to root growth (Drew and Ledig 1980). Studies showed that pine growth is usually slow on poorly drained sites (Derr and Mann 1977). There is a strong positive relationship between water table depth in winter and slash pine growth (McKee and Shoulders 1970, Haywood et al. 1990).

Survival and growth data indicate thus far that use of CRC can extend the planting season by allowing planting as early as September and as late as March. These results suggest that CRC, with its superior and steady survival and often better initial height growth, thus far have out-performed BRS.

Figure 13. Top: slash pine CRC planted in April 2001 on Site I showing substantial growth variation with many stunted trees three years after planting. Bottom: CRC (left) and BRS (right) planted in September 2000 on Site III. Picture shows uniformity within rows at the end of the third growing season.

CHAPTER III

GAS EXCHANGE, CARBON ISOTOPE DISCRIMINATION AND EARLY BIOMASS ALLOCATION PATTERNS OF FIELD GROWN SLASH PINE (*Pinus elliottii* Engelm.) BARE-ROOT SEEDLINGS AND CONTAINERIZED ROOTED CUTTINGS

Introduction

Photosynthesis is the most important physiological process in plants since growth depends on carbohydrates produced by the process (Kramer and Kozlowski 1960). Photosynthesis rates are affected by water deficits and can be completely limited by low water potentials. For instance, net photosynthesis of loblolly pine seedlings was completely inhibited at water potentials (ψ) of -2.0 MPa (Teskey et al. 1986, Seiler and Johnson 1988) whereas for established loblolly pine, photosynthesis approached zero at lower (-3.0 MPa) values (Tang et al. 1999). Water deficits have both short-term and long-term consequences (Myers 1988). Tree growth is reduced by water deficits affecting physiological processes (Kramer 1962). Water stress often causes mortality and early growth reductions in newly planted trees (Kozlowski and Davies 1975). Mortality in new plantations is most likely to occur in the first spring or summer because of the limited root development of these newly planted trees (Long 1991). Slash pine seedlings with smaller root systems had more water stress and mortalities compared to those with bigger root systems (Mcgrath and Duryea 1994).

Because containerized stock has undisturbed intact root systems compared to damaged root systems of bare-root seedlings caused by lifting, containerized stock has a shorter period of transplanting shock or adjustment (Barnett and McGilvray 2000). Thus, containerized stock has higher survival and greater early growth rates compared to bare-root stock (Mann 1977, Guldin 1981, Barnett 1984, Shaw 1985, Boyer 1988, Barnett and McGilvray 1993).

Foliar carbon isotope composition ($\delta^{13}C$) can provide information about time-integrated plant physiological response (Flanagan and Ehleringer 1998). Carbon isotope composition reflects the time-integrated ratio of internal to ambient CO_2 concentrations (p_i / p_a) (Parasolova et al. 2003). This ratio (p_i / p_a) is a function of both photosynthetic capacity and stomatal conductance. Carbon isotope discrimination is negatively related to plant water use efficiency (WUE, ratio of net CO_2 assimilation / transpiration). Carbon isotope composition is commonly used to study the time-integrated WUE of trees (Cregg and Zhang 2001, Ponton et al. 2001) and other species (Donovan and Ehleringer 1994). The $\delta^{13}C$ values range between -22‰ and -34‰ for terrestrial C_3 plants grown under natural conditions (Vogel 1993). For slash pine x Caribbean pine (*Pinus caribaea*) hybrids, $\delta^{13}C$ ranged between -25‰ and -29.5‰ (Parasolova et al. 2003).

The balance between above- and belowground biomass allocation is highly dependent on limiting environmental factors (Johnson 1990). This balance is affected by factors like light (Barney 1951), water availability (Monk 1966, Kozlowski and Davies 1975, Johnson 1990) and nutrient availability (Johnson 1990, Dewald et al. 1991) to the plants.

The goals of this study were to determine 1) how planting time affects the photosynthetic capacity of bare-root seedlings and containerized rooted cuttings, 2) how carbon isotope composition changes between stock types planted on different dates, 3) how planting date affects the early biomass allocation of bare-root seedlings and containerized rooted cuttings.

Methods and Materials

Study Sites

Two sites, one in Beauregard Parish and one in Calcasieu Parish within 22 km of each other in southwestern Louisiana were chosen for this study (30° 33' N - 93° 37' W; 30° 23' N - 93° 30' W) Originally three sites were selected; however, Site II at Jack Bennette Road was abandoned due to flooding and poorly-formed beds. Therefore, only Sites I and Site III are discussed. The sites had similar soil types and site preparation and management history. The soils were very deep, poorly to somewhat poorly drained, silt loam Alfisols on nearly level to very gently sloping terraces of mid-to-late-Pleistocene age. These soils had a Bt (restrictive argillic) horizon and depth to this horizon was between 15-50 cm. The surface and subsoil textures were silt loam and silt clay loam, respectively. Soils at both sites were within the Caddo-Messer complex. Site I at Bailey Road was flat and poorly drained whereas Site III at Persimmon Road was located on a broad ridge and thus had greater surface drainage, although it was somewhat poorly drained internally. The climate is warm and humid with an average winter temperature of 11 °C and average summer temperature of 28 °C. Total annual precipitation averages 148 cm and is well distributed throughout the year (recorded from 1971-2000 at DeQuincy weather station, LA). The study sites, previously planted with slash pine stands, were clearcut and mechanically bedded with a combination plow before the study. Prior to planting, sites were sprayed with triclopyr and glyphosate to control competing vegetation. After planting, hexazinone and sulfometuron methyl was applied to control herbaceous vegetation and to promote uniformity across sites.

Planting Stock and Study Establishment

Planting stock tested in this study was slash pine bare-root seedlings (BRS) and containerized rooted cuttings (CRC). The BRS were produced through standard nursery culture at the Beauregard Nursery near Merryville, LA. Slash pine seeds were sown mid- to late April. Nursery beds consisted of eight rows with 16.5 cm between rows of seedlings. Seedlings were laterally and horizontally root pruned to ensure more compact, fibrous root systems. They were also top pruned to 23 cm to increase seedling uniformity and root:shoot ratio. The CRC were produced by Boise Corporation at their seed orchard near Evans, LA. Cuttings were harvested from less than three-year-old full-sib slash pine hedges. Two main crops were taken from the same hedges in April and June throughout the study period. Cuttings were rooted in 12.5-cm deep, 220-cm^3 containers at a density of 277/m^2. Growing media consisted of 40% perlite and 60% peat by volume. The first crop was used for September and November plantings and the second crop was used for January, March and April plantings. CRC were full-sib and BRS were half-sib in the 2000-2001 and 2002-2003 planting season. They had one parent in common, whereas both CRC and BRS were full-sib from the same family in the 2001-2002 planting season. Both CRC and BRS were hand planted at 1.8-m X 3.4-m spacing. Bare-root seedlings were lifted and planted on the same day except for April 2003, which used seedlings lifted in March 2003 and kept refrigerated until planting. All trees were fertilized at planting with diammonium phosphate at the equivalent of 225 kg/ha.

Study Design and Statistical Analysis

Each location was planted on five different dates (September, November, January, early March, late April) in three planting seasons (2000-2001, 2001-2002, and 2002-2003). A split-plot design was used with planting date as the main plot and stock type as the sub-plot. Trees were planted in 20-tree rows with ten replications per site-year. Within-row spacing was 1.8 meters; between-row spacing was approximately 3.35 meters, or standard between-row spacing as determined by bedding machinery. Analysis of variance was performed using the General Linear Model procedure of SAS (SAS Institute 1997). Unless otherwise stated, α=0.05 was used as a critical significance level. Mean separations were tested using the Duncan's new multiple range test method when necessary.

Data Collection

Water relations and gas exchange

Predawn and diurnal (0900, 1200, 1500, 1800 hours) needle water potentials (ψ) were measured on July 19 and Aug 30, 2002 with a pressure bomb apparatus (PMS Instrument Co., Corvallis, OR, USA) on three randomly selected plots on Site I. Eighteen randomly selected trees (six on each plot) were used for all measurement hours. They consisted of equal numbers of BRS and CRC from the September 2001, January 2001, and April 2002 plantings. Physiological response of each stock type was assessed through measurement of net photosynthesis (A_n), stomatal conductance (g_s), and transpiration (E) at 0900,1200,1500,1800 hours with a Li-Cor 6200 portable photosynthesis system (Lincoln, NE, USA) in two measurement sessions on July 19 and August 30, 2002, on the same trees used for ψ. Needles from the upper third of the southern side of the crown were selected for measurements. A single fascicle was used for each measurement. Photosynthetic photon flux density (PPFD) was measured using a Li-Cor LI-190 quantum sensor attached to the Li-Cor 6200 portable photosynthesis system. Needle ψ and net photosynthesis rates were also determined in the 2003 growing season on May 30 and August 7 on the same trees, but measurements were made between 1200 and 1500 hours during cloud-free periods to measure light saturated photosynthesis.

Carbon isotope discrimination

In January 2002 from Site I and in January 2003 from both sites, six fascicles from three trees on three randomly selected plots were collected from all stock types x three planting months (September, January and April) combinations for stable carbon isotope composition determination. The January 2002 sampling consisted of trees planted only in the 2000-2001 planting season whereas the January 2003 sampling also included trees planted in the 2001-2002 planting season. Foliage samples were collected from the upper third of the canopy. Foliage samples were oven-dried at 70 °C to constant weight and ground to a fine powder. The relative abundance of 13C and 12C was determined at the UC Davis Stable Isotope Facility (University of California, Davis, CA, USA) using a mass spectrometer (Integra-CN; Europa S. Instruments, Cheshire, UK). The δ^{13}C was calculated using the formula below,

$$\delta^{13}\mathrm{C} = \left[\frac{R_{\mathrm{sample}}}{R_{\mathrm{standard}}} - 1\right] \times 1000‰$$

where δ^{13}C is the isotope ratio in parts "per mil" (‰), R_{sample} is ^{13}C/^{12}C ratio of the sample and R_{standard} is the Pee Dee Belemnite (PDB) standard (O`Leary 1993). Data were used to investigate the differences in integrated photosynthetic activity and water use efficiencies during the previous growing season.

Destructive sampling

Twenty trees from each site from the 2000-2001 planting season were extracted by shovel (two from each planting month x five planting dates x two stock types x two locations) on February 7, 2002. Time since planting varied from 36 weeks for the September 2000 trees to seven weeks for the April 2001 trees. On February 7, 2002, when trees were 43 to 72 weeks in the ground, a total of 40 more trees from the same planting month, stock type and location combinations were extracted using an air excavator tool (CEG Inc., Pittsburg, PA, USA). Samples were washed manually using tap water and oven-dried at 70 °C. Dry weights of needles, stems, and roots were determined, and root:shoot and root:needle ratios were calculated.

Meteorological data

Meteorological instruments and CR10X dataloggers (Campbell Scientific Inc., Logan, UT, USA) were installed on each site for continual collection of environmental data. Rainfall was recorded with a tipping bucket rain gauge and soil moisture (0-30 cm deep) was recorded hourly with a time domain reflectometry probe on each site. Vapor pressure deficit was calculated based on air temperature and relative humidity values obtained from a weather station at a nearby site, which was located 8 km south of the first site.

Results

Water Relations and Gas Exchange

Water potential (ψ)

There was no significant difference between stock types or among months in pre-dawn water potential (ψ) measured in both sessions (July 19 and August 30, 2002) (Figure 14). Needle ψ was high (mean of -0.65 and -0.38 MPa, respectively, for July 19 and August 30) for all months and stock types early in the morning and decreased throughout the day until the 1800-hour measurement when there was a slight increase in water potential of about 0.5 MPa.

There was no significant ψ difference between stock types at all hours on July 19. On August 30, 2002, BRS had significantly lower ψ compared to CRC only at noon.

Water potential did not vary significantly among planting months on Aug 30, 2002. However, planting months significantly (P<0.0001) affected ψ on July 30, 2002. Water potential was highest in September trees from 0900 hours through 1500 hours on July 19, followed by January trees. April trees had the lowest value of -1.87 MPa at 1500 hours on July 19. Total rainfall was 69.6 mm in the 15 days preceding July 19, 2002 and 144 mm preceding August 30 on Site I. Vapor pressure deficit (VPD) was higher on July 19, 2002 compared to August 30, 2002. Vapor pressure deficit varied from 0.6 kPa at 0900 hours to 2.7 kPa at 1200 hours on July 19, whereas it was 0.3 kPa at 0900 hours and 2.0 kPa at 1200 hours on the latter date. Soil moisture was slightly higher on July 19, compared to August 30. Similarly, ψ on July 19, 2002 was higher than the ψ measured on Aug 30, 2002.

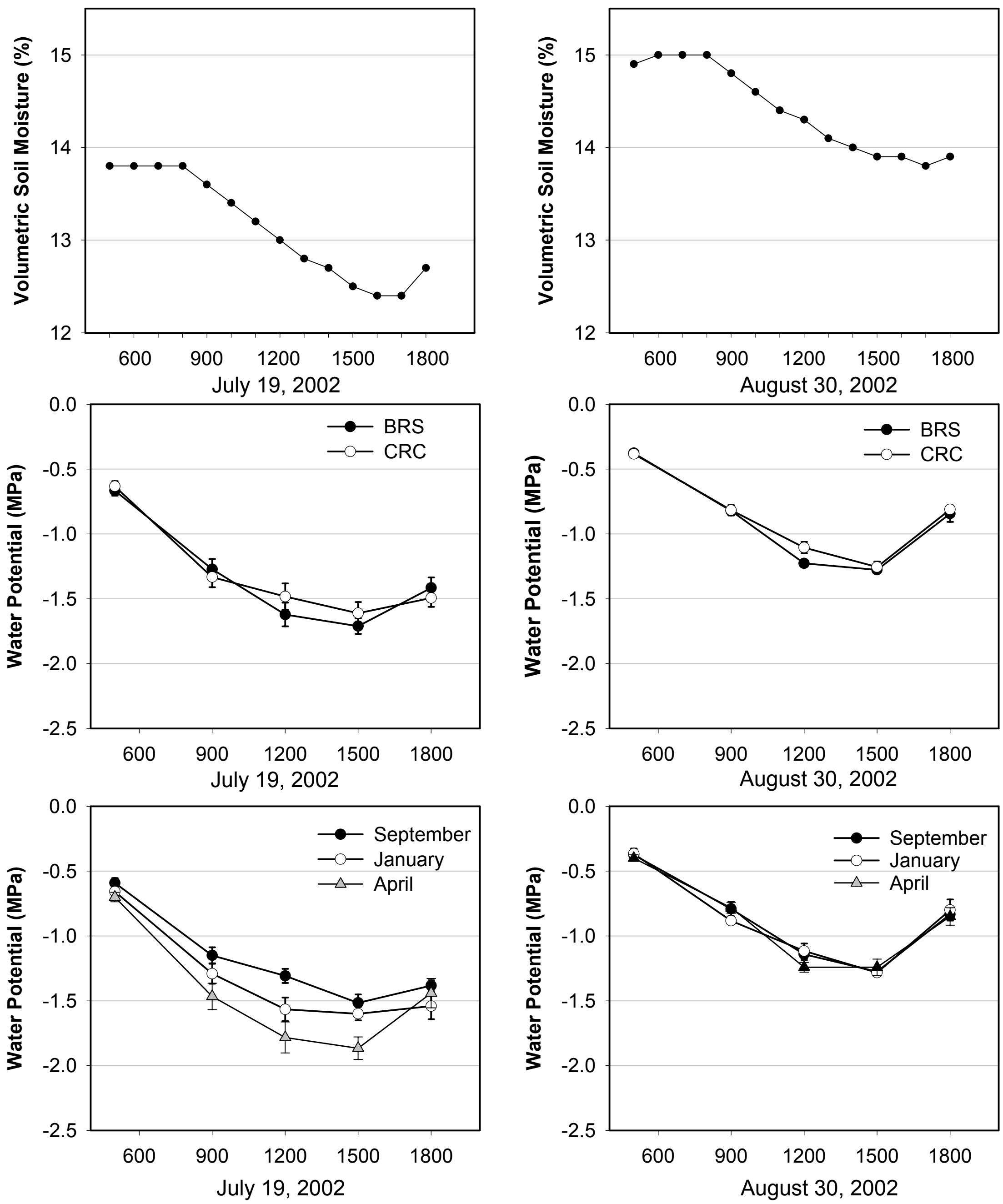


Figure 14. Top row: Hourly volumetric soil moisture content (0-30 cm) measured on July 19 and August 30, 2002 on Site I near Merryville, LA. Middle and bottom rows: Predawn and diurnal (0900, 1200, 1500, 1800 hours) water potentials of slash pine trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001 and April 2001 on the same site. Middle row shows means by stock type across planting months. Bottom row shows means by planting month across stock types. Vertical bars indicate one standard error.

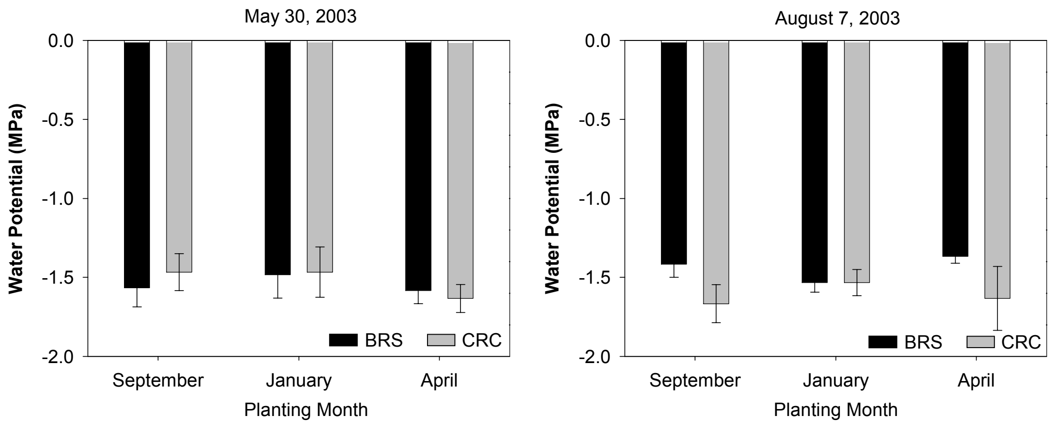


Figure 15. Water potentials of slash pine trees in two measurement sessions on May 30 and August 07, 2003 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001 and April 2001. Vertical bars indicate one standard error.

No significant ψ difference was observed between BRS and CRC in the 2003 measurements (Figure 15). Average ψ of BRS and CRC were -1.54 and -1.52 MPa on May 30, 2003 and -1.44 and -1.61 MPa on August 7, 2003, respectively. Water potentials did not vary among planting months on August 7, however on May 30, April-planted trees had an average ψ of -1.61 MPa which was significantly lower than those of September (-1.52 MPa) and January (-1.48 MPa).

Total rainfall was seven millimeters in the 15 days preceding May 30 and 19 mm preceding August 7 on Site I. However, average soil moisture was slightly lower on August 7 (11%) than on May 30 (12.3 %). Vapor pressure deficit ranged from 2.3 kPa at 1200 hours to 2.9 at 1500 hours during measurements on May 30, whereas it was 1.5 kPa at 1200 hours and 3.2 kPa at 1500 hours on August 7.

Stomatal conductance (g_s)

There was no significant difference between stock types or among planting months in stomatal conductance (g_s) measured on July 19, 2002 (Figure 16). However, both planting month and stock type significantly affected g_s on August 30, 2002.

Although BRS had consistently higher average g_s throughout all measurement hours on August 30, 2002, this was significant only at noon where g_s averaged 0.36 and 0.33 cm s^{-1} for BRS and CRC, respectively. During the morning and evening measurement hours (at 0900 and 1800 hours), April-planted trees exhibited higher average g_s than other months for both measurement sessions in 2002.

Average g_s across planting months and stock types was higher in the early morning at 0900 hours on July 19 compared to that of August 30 (0.70 and 0.46 cm s^{-1}, respectively) and decreased throughout the day. However average g_s observed on August 30 was more consistent throughout the day (Figure 16). Lowest average g_s (0.27 cm s^{-1}) across stock types and planting dates in 2002 measurements was observed at 1800 hours on July 19, when average photosynthetic photon flux density (PPFD) was lowest (178 μmol m^{-2} s^{-1}) among all measurement hours in 2002.

Stomatal conductance did not vary significantly between stock types during 2003 measurements (Figure 17). Mean g_s was 0.10 cm s^{-1} for CRC and 0.11 cm s^{-1} for BRS on August 7, and was 0.14 cm s^{-1} for both stock types on May 30.There was no significant difference in g_s among planting months on May 30. During the August measurement session, mean g_s for trees planted in different months varied from 0.09 to 0.13 cm s^{-1} and were significantly higher in April-planted trees compared to that of January-planted ones.

Transpiration (E)

Neither planting month nor stock type had a significant effect on transpiration (*E)* measured on July 19, 2002 (Figure 18). On August 30, BRS had significantly higher average *E* compared to CRC across all measurement hours (0.0054 and 0.0050 mol m^{-2} s^{-1}, respectively). On the same date, average *E* of April-planted trees was significantly higher compared to that of trees planted in September

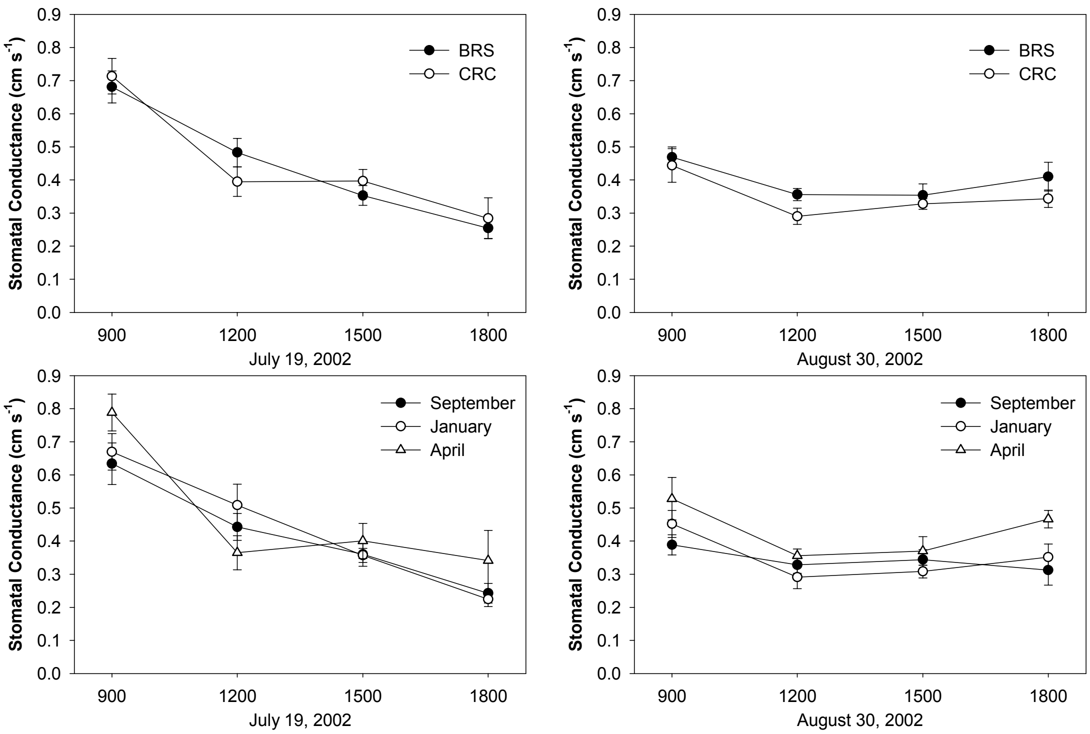


Figure 16. Stomatal conductance of slash pine trees in two measurement sessions on July 19 and August 30, 2002 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001, and April 2001. Vertical bars indicate one standard error.

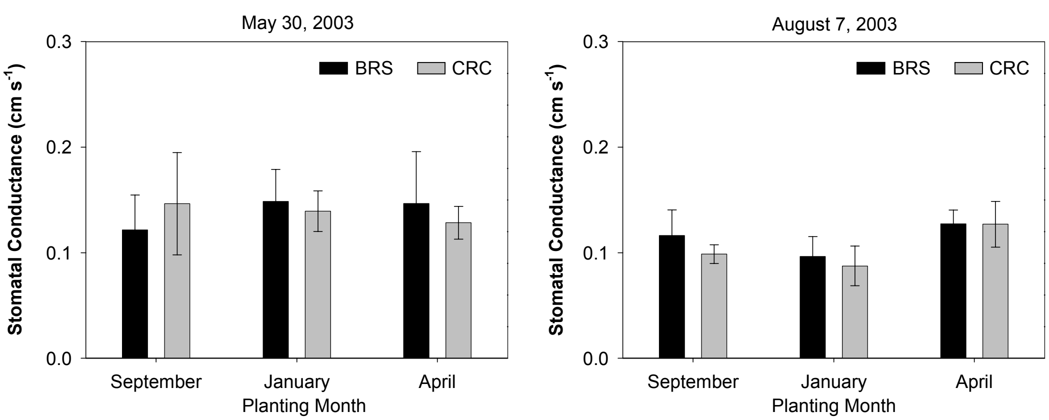


Figure 17. Stomatal conductance of slash pine trees in two measurement sessions on May 30 and August 07, 2003 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001 and April 2001. Vertical bars indicate one standard error.

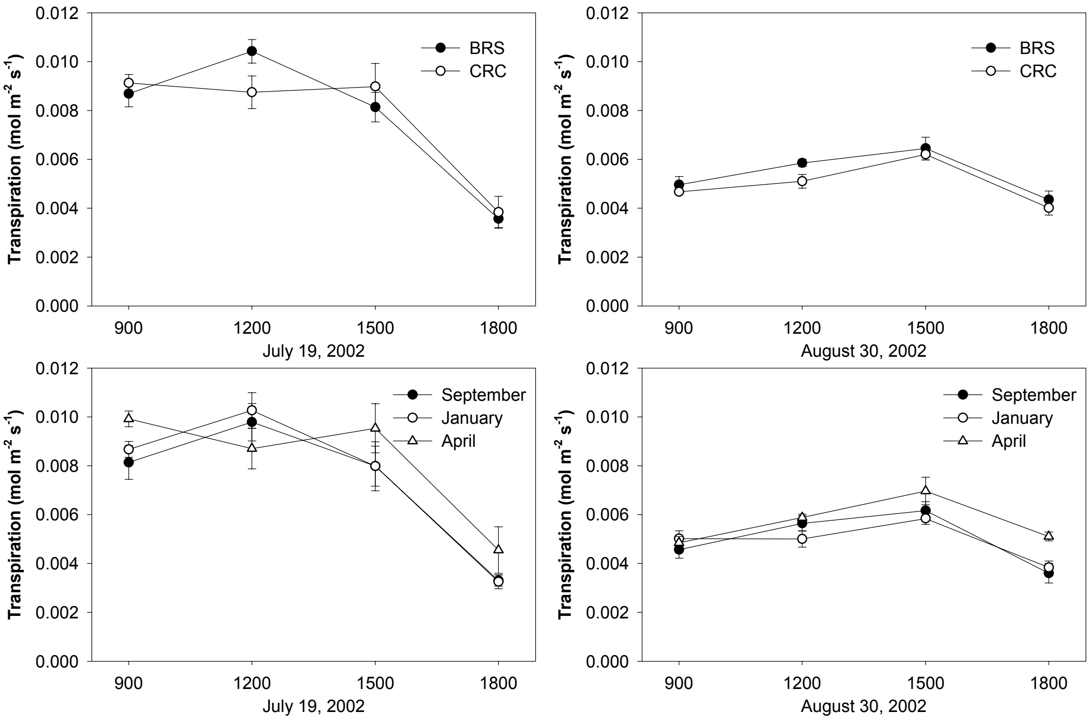


Figure 18. Transpiration of slash pine trees in two measurement sessions on July 19, 2002 and August 30, 2002, on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001, and April 2001. Vertical bars indicate one standard error.

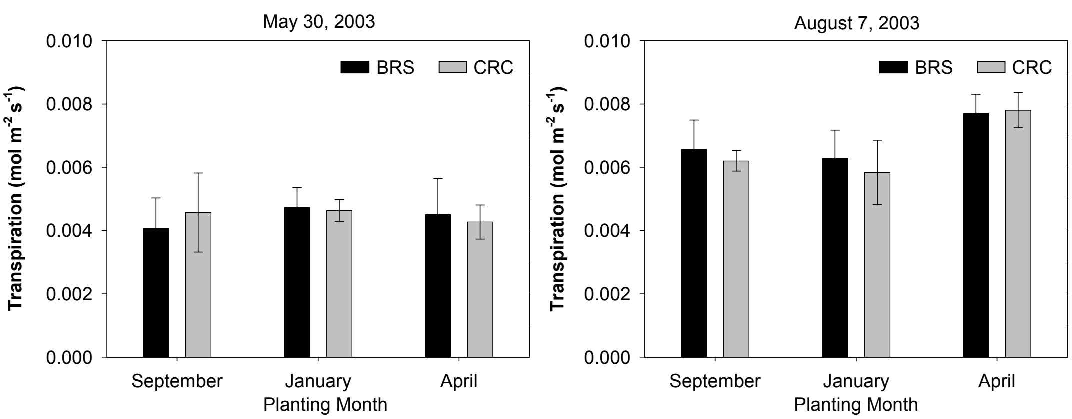


Figure 19. Transpiration of slash pine trees in two measurement sessions under light-saturated conditions on May 30 and August 07, 2003 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001, and April 2001. Vertical bars indicate one standard error.

and January (0.0057, 0.0050, 0.0049 mol m^{-2} s^{-1} respectively). Bare-root seedlings had significantly higher *E* than CRC at noon for both measurements in 2002 (Figure 18).

Although it varied among months and stock types, the highest average *E* across planting months and stock types was observed at 1200 hours (0.0096 mol m^{-2} s^{-1}) on July 19, 2002 and at 1500 hours (0.0063 mol m^{-2} s^{-1}) on August 30, 2002 (Figure 18). Transpiration rates were higher on July 19, 2002 than on August 30 for all measurement hours except at 1800 when rates were comparable.

Average *E* across planting dates and stock types were comparable between 0900 and 1500 hours on July 19, 2002, until they dropped from 0.0086 mol m^{-2} s^{-1} at 1500 hours to 0.0037 mol m^{-2} s^{-1} at 1800 hours (Figure 18). On August 30, 2002, average *E* slightly increased from early in the morning to the afternoon, and then decreased to the lowest observed value for the day of 0.0042 mol m^{-2} s^{-1} at 1800 hours.

Average *E* among planting months varied from 0.0061 to 0.0078 mol m^{-2} s^{-1} on August 7, 2003, and was significantly higher for the April-planted trees compared to January and September trees (Figure 19). On May 30, 2003, average *E* varied from 0.0043 mol m^{-2} s^{-1} for September-planted trees to 0.0047 mol m^{-2} s^{-1} for January-planted trees but did not differ significantly among months. Both stock types had comparable *E* during measurement sessions in 2003 (Figure 19).

Photosynthesis (A_n)

Net photosynthesis (A_n) was *not* affected by stock type or by planting dates on any of the measurements for both years.

Net photosynthesis was highest at 0900 hours for both measurement sessions in 2002 (Figure 20). Averaged across planting months by stock type, higher A_n values were observed at 0900 hours on July 19 than on August 30 although trees had lower needle ψ. April-planted trees had a sharp decrease in A_n from 0900 hours to 1200 hours on July 19 when average ψ decreased from -1.5 MPa to -1.8 MPa. As ψ decreased from 0900 hours through 1500 hours, A_n measured on two dates became more comparable. Net photosynthesis was lowest (2.2 μmol m^{-2} s^{-1}) on July 19, 2002 at 1800 hours when average PPFD was 178 μmol m^{-2} s^{-1} (Figure 20).

Net photosynthesis and g_s had similar patterns. Net photosynthesis on August 30 was flatter throughout the day than on July 19, 2002. However, average A_n decreased from 1500 hours to 1800 hours on August 30, 2002 whereas average g_s values increased slightly between the same hours.

Net photosynthesis varied from 2.8 μmol m^{-2} s^{-1} (for September-planted trees) to 3.2 μmol m^{-2} s^{-1} (for April-planted trees) on May 30, 2003 (Figure 21). On August 7, 2003 mean A_n was between 5 (for September-planted trees) and 6 μmol m^{-2} s^{-1} (April-planted trees). This variation was not statistically significant.

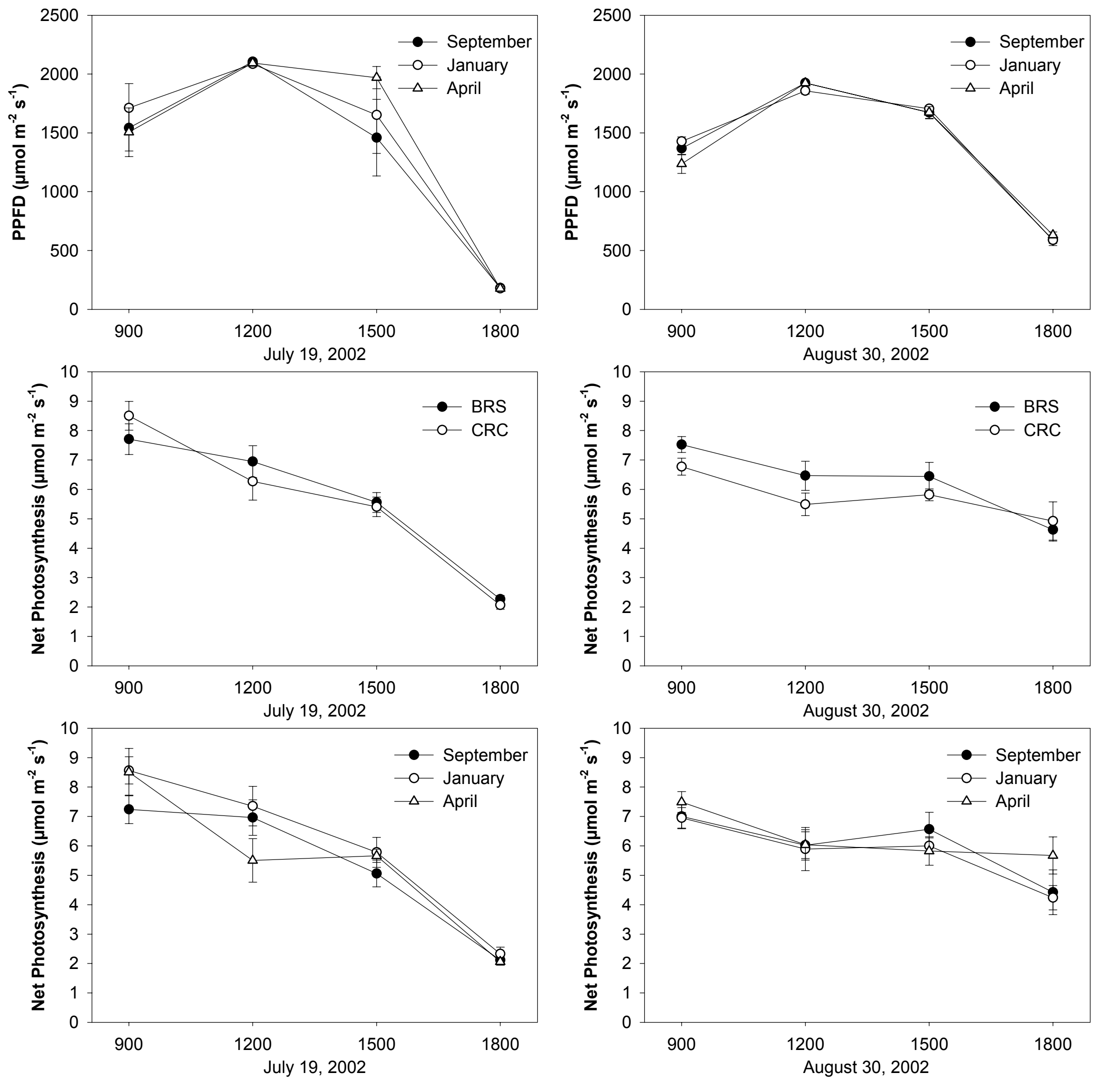


Figure 20. Net photosynthesis rates of slash pine trees and photosynthetic photon flux density during two measurement sessions on July 19 and August 30, 2002 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001, and April 2001. Vertical bars indicate one standard error.

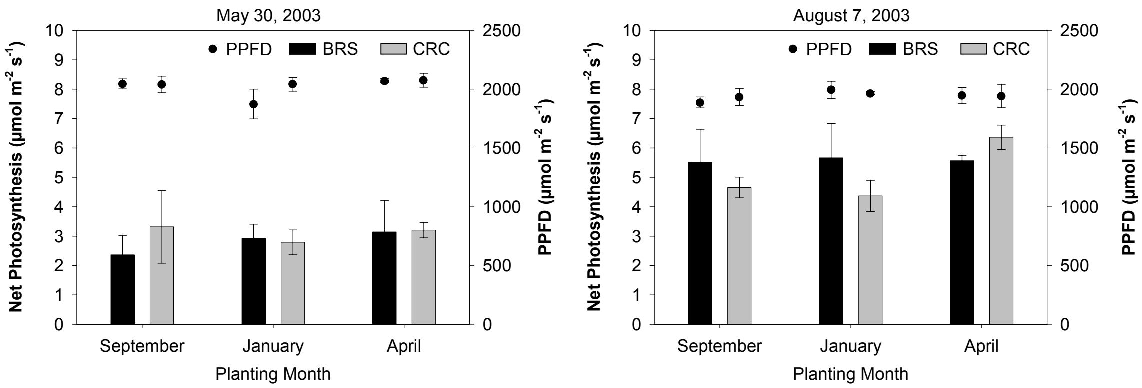


Figure 21. Net photosynthesis rates of slash pine trees and photosynthetic photon flux density during two measurement sessions under light-saturated conditions on May 30 and August 07, 2003 on Site I near Merryville, LA. Trees established as containerized rooted cuttings and bare-root seedlings in September 2000, January 2001, and April 2001. Vertical bars indicate one standard error.

Carbon Isotope Discrimination

2001 growing season

April-planted trees had significantly (*P*<0.0001) less negative $\delta^{13}C$ values (i.e. closer to zero) than did September- and January-planted trees in their first mutual growing season on Site I (Figure 22). Carbon isotope ratio did not differ significantly between BRS and CRC, although BRS had consistently less negative $\delta^{13}C$ values. Carbon isotope ratio varied between -29.3 ‰ for April BRS to -30.5 ‰ for September CRC.

2002 growing season

Trees planted in the 2000-2001 planting season had less negative $\delta^{13}C$ values than did the 2001-2002 planted trees on both sites. On poorly drained Site I, this difference was significant (Table 5). Carbon isotope ratio did not differ significantly between stock types or among planting dates in the 2002 growing season for the 2000-2001 planted trees on either Site I (Figure 22) or Site III (Table 5). Trees planted in the 2000-2001 season on Site III had significantly less negative (*P*=0.0002) $\delta^{13}C$ values compared to those of Site I.

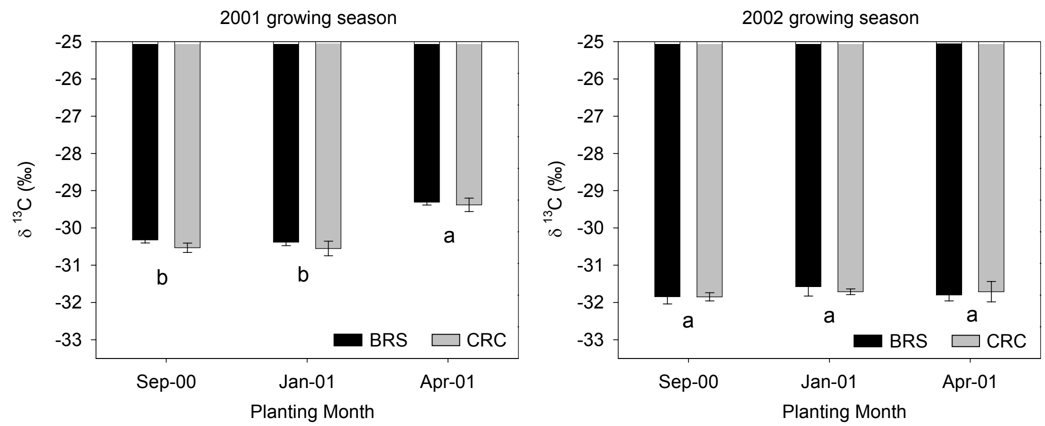


Figure 22. Carbon isotope composition (δ13C, ‰) in 2001 (left) and 2002 (right) growing seasons in slash pine bare-root seedlings and containerized rooted cuttings planted on three different dates (September 2000, January 2001, and April 2001) on Site I near Merryville, LA. Error bars indicate one standard error. Letters are statistical differences for months as a main effect.

Foliar $\delta^{13}C$ of trees planted in 2001-2002 on Site III differed significantly between stock types and the planting dates. Bare-root seedlings had significantly higher (i.e. less negative) (0.73 ‰ higher) $\delta^{13}C$ than did CRC on this better-drained site. Also, foliar $\delta^{13}C$ of April-planted trees was less negative than that of the September-planted trees on Site III (Table 5). However, $\delta^{13}C$ did not vary significantly between stock types or among planting dates in the 2001-2002 planted trees on Site I.

Table 5. Carbon isotope composition ($\delta^{13}C$, ‰) of slash pine leaf tissue from bare-root seedlings and containerized rooted cuttings planted between September 2000 and April 2002 on two sites in southwestern Louisiana. Numbers in parentheses are standard errors. Main effects *within groups* followed by the same letter are not significantly different (α = 0.05) according to Duncan's new multiple range test.

	Site I (Bailey Road Site)				Site III (Persimmon Road Site)		
Planting date	BRS	CRC	BRS&CRC		BRS	CRC	BRS&CRC
2000-2001 Planting							
September 2000	-31.84(0.19)	-31.85(0.11)	-31.85(0.10) a^{+}	September 2000	-30.98(0.22)	-31.37(0.08)	-31.18(0.14) a^{+}
January 2001	-31.58(0.25)	-31.71(0.08)	-31.64(0.12) a^{+}	January 2001	-31.56(0.17)	-31.16(0.22)	-31.36(0.15) a^{+}
April 2001	-31.80(0.16)	-31.71(0.27)	-31.75(0.14) a^{+}	April 2001	-31.46(0.24)	-31.20(0.28)	-31.33(0.17) a^{+}
	-31.74(0.11) a^{x}	-31.76(0.09) a^{x}			-31.33(0.14) a^{x}	-31.24(0.11) a^{x}	
	-31.75(0.07) b$^{\#}$				-31.29(0.09) a$^{\#}$		
2001-2002 Planting							
September 2001	-31.04(*)	-31.19(0.16)	-31.16(0.12) a^{+}	September 2001	-31.08(0.28)	-31.58(0.14)	-31.33(0.18) b^{+}
January 2002	-31.02(0.37)	-31.64(0.19)	-31.33(0.23) a^{+}	January 2002	-30.52(0.06)	-31.51(0.16)	-31.02(0.23) ba^{+}
April 2002	-30.98(0.44)	-31.53(0.15)	-31.25(0.24) a^{+}	April 2002	-30.57(0.16)	-31.28(0.13)	-30.93(0.18) a^{+}
	-31.01(0.22) a^{x}	-31.45(0.11) a^{x}			-30.73(0.13) a^{x}	-31.46(0.08) b^{x}	
	-31.26(0.12) a$^{\#}$				-31.09(0.12) a$^{\#}$		

^{x}denotes comparison between stock types.
$^{+}$denotes comparison among months
$^{\#}$denotes comparison between sites.
*Only one sample was taken on this site from planting year x planting month x stock type combinations.

Plant Biomass

Containerized rooted cuttings planted in the 2000-2001 planting season had significantly higher root dry weight, needle dry weight, and stem dry weight than did BRS after 7- to 36-weeks in the ground on May 30, 2001. However, BRS had significantly higher root:shoot ratios and root:needle ratios than did CRC on this date (Table 6). On May 30, 2001, trees planted in April 2001 (when seven-weeks in the ground) had significantly higher root:shoot ratios and root:needle ratios than did trees planted from September 2000 through March 2001 (when 36 to 11-weeks in the ground) (Table 6). September-planted trees had the highest root, needle and stem dry weights, whereas April-planted trees had the lowest. March- and April-planted trees did not significantly differ in root and stem dry weights. Also November and March plantings had comparable root, stem and needle dry weights. There was a significant planting month x stock type interaction for tree component weights and ratios. Root:shoot and root:needle ratio differences between stock types were notable from January through April plantings (Figure 23). Trees on different sites did not differ significantly in dry weights and ratios on the May 2002 measurement. On the May 2002 measurement, root:shoot ratios of BRS decreased as time since planting increased (7- to 36 weeks) and total plant dry mass increased (Figure 24a). However, CRC planted September through March (36 to 11 weeks on in ground) did not show this trend on the same measurement date (Figure 24a).

On February 7, 2002, when trees were in the ground for 43 to 72 weeks, CRC still had significantly higher root dry weight, stem dry weight, and root:needle ratios than did BRS (Table 6). Trees planted in April had significantly higher root:shoot ratios than did March, November and September trees. September-planted trees still had the highest root, needle and stem dry weights, whereas April-planted trees had the lowest. November, January and March plantings did not differ significantly in root, needle and stem dry weights; however, they had

Table 6. Tree component dry weights and ratios from two destructive sampling sessions on two sites in southwestern Louisiana. Trees established as bare-root seedlings and containerized rooted cuttings in the 2000-2001 season. Only main effects are shown. Numbers in parentheses are standard errors. Main effects within groups followed by the same letters are not significantly different (α = 0.05) according to Duncan's new multiple range test.

Main effects	Dry weights (g)			Ratios of dry weights	
	Root	Stem	Needle	Root:shoot	Root:needle
May 30, 2001 sampling					
September 22, 2000 [36*]	6.3(0.5) a	11.0(1.0) a	18.2(1.6) a	0.22(0.01) c	0.35(0.01) c
November 9, 2000 [29*]	5.0(0.6) b	6.6(0.9) b	11.8(2.0) b	0.28(0.02) cb	0.44(0.02) cb
January 11, 2001 [20*]	4.5(0.7) b	6.6(1.4) b	9.8(2.1) b	0.34(0.05) cb	0.57(0.10) cb
March 12, 2001 [11*]	2.5(0.3) c	2.7(0.5) c	4.6(0.8) c	0.41(0.07) b	0.64(0.11) b
April 12, 2001 [7*]	1.8(0.2) c	1.4(0.2) c	1.8(0.2) d	0.57(0.06) a	1.06(0.14) a
Bare-root seedlings	3.4(0.3) b	4.5(0.8) b	6.6(1.3) b	0.43(0.04) a	0.76(0.09) a
Cont. rooted cuttings	4.6(0.6) a	6.9(1.0) a	11.8(1.7) a	0.29(0.03) b	0.47(0.05) b
Site I (Bailey Rd. Site)	3.8(0.5) a	5.4(0.9) a	9.2(1.6) a	0.35(0.03) a	0.57(0.06) a
Site III (Pers. Rd. Site)	4.2(0.5) a	5.9(1.0) a	9.2(1.6) a	0.38(0.04) a	0.66(0.09) a
February 7, 2002 sampling					
September 22, 2000 [72*]	125.6(15.9) a	127.9(16.1) a	119.8(13.7) a	0.52(0.05) b	1.06(0.09) a
November 9, 2000 [65*]	82.6(7.2) b	79.8(7.3) b	73.9(6.5) b	0.54(0.03) b	1.14(0.08) a
January 11, 2001 [56*]	85.1(19.4) b	70.9(16.7) b	75.8(17.8) b	0.58(0.04) ab	1.14(0.08) a
March 12, 2001 [47*]	86.9(18.3) b	71.1(11.5) b	73.9(13.5) b	0.56(0.05) b	1.11(0.08) a
April 12, 2001 [43*]	20.1(2.5) c	13.6(1.8) c	16.7(2.4) c	0.69(0.06) a	1.26(0.11) a
Bare-root seedlings	66.1(10.6) b	60.9(10.3) b	64.7(10.6) a	0.55(0.03) a	1.06(0.06) b
Cont. rooted cuttings	94.0(11.8) a	84.4(11.3) a	79.4(10.1) a	0.61(0.03) a	1.22(0.05) a
Site I (Bailey Rd. Site)	63.5(9.6) b	67.6(11.1) a	64.3(9.7) a	0.51(0.03) b	1.01(0.05) b
Site III (Pers. Rd. Site)	96.6(12.3) a	77.7(11.0) a	79.7(11.0) a	0.65(0.02) a	1.27(0.04) a

* Number of weeks since planting.

lower weights than did September-plantings and higher weights than did April plantings. Trees planted on Site III had significantly higher root dry weights, and root:shoot and root:needle ratios than did those planted on Site I. As trees got older, root:shoot ratio differences among planting months with respect to total tree dry weights decreased (Figure 24b).

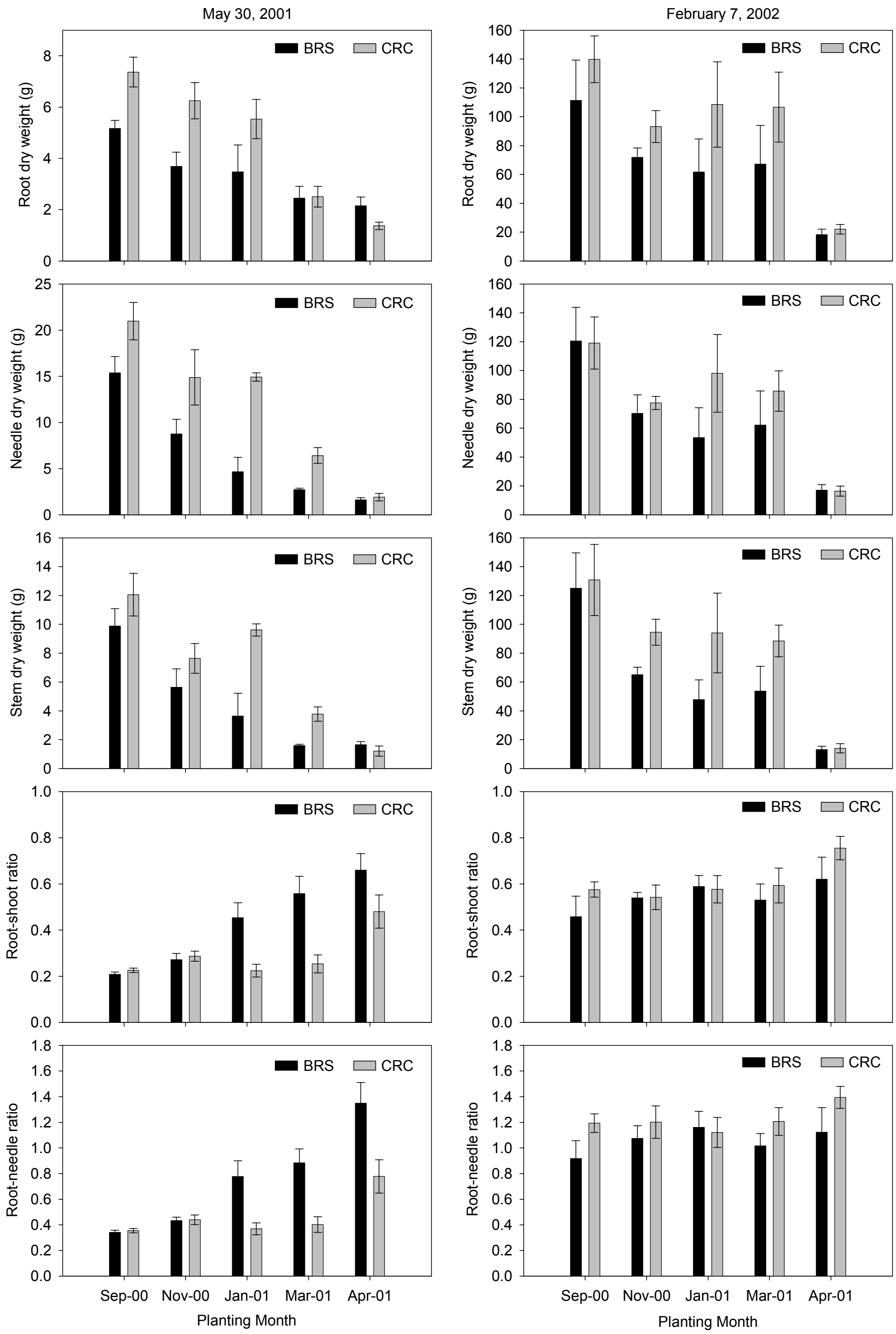


Figure 23. Tree component dry weights and ratios from two destructive sampling sessions on Site I and Site III in southwest Louisiana. Each column shows the average values of two sites. Trees established as bare-root seedlings and containerized rooted cuttings in the 2000-2001 season. Vertical bars indicate one standard error.

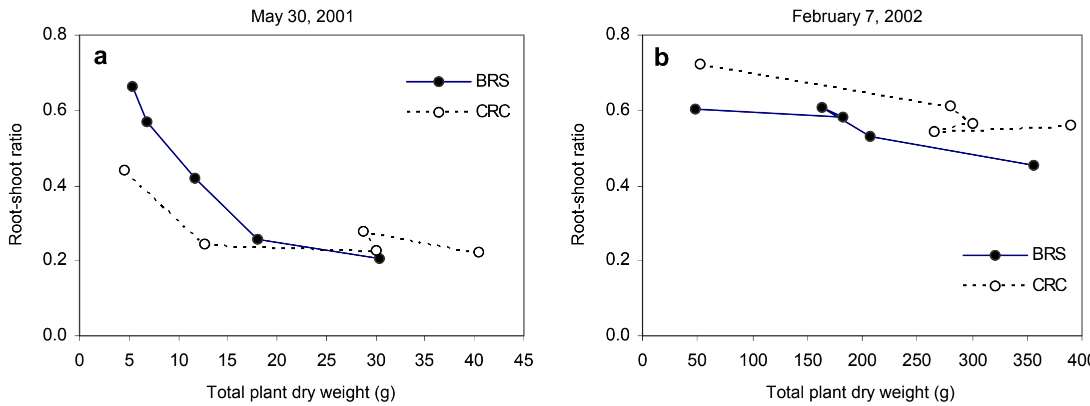


Figure 24. Root:shoot ratio of slash pine containerized rooted cuttings and bare-root seedlings with respect to total tree dry weights on May 30, 2001 (a), and on Feb 7, 2002 (b). Each point represents the average of four trees. Points represent September to April planting from right to left. Trees planted between September 2000 and April 2001. Time since planting varied between 7 and 36 weeks on May 30, 2001 sampling and 43 and 72 weeks on February 2002.

Discussion

Predawn and diurnal variation in needle ψ consistently reflected the variation in soil moisture in 2002. When volumetric soil moisture content was 15%, there was no consistent variation in needle ψ among trees planted in different months on July 19, 2002. When volumetric soil moisture was as low as 13.6%, trees planted in earlier months showed higher needle ψ compared to April trees. These results are consistent with findings of Radoglu et al. (2003) for chestnut (*Castanea sativa* Mill.) seedlings. Leaf water potential (ψ) of chestnut seedlings planted in February and March was lower than those of trees planted in December and January, and late in the summer this difference was significant (Radoglu et al. 2003).

The lowest predawn and diurnal needle ψ observed were -0.65 MPa and -1.87 MPa, respectively, on July 19. Photosynthesis rates on this date indicate that water supply was probably sufficient for gas exchange. Teskey et al. (1994) found that A_n was not limited by water deficit when predawn Ψ was as low as -0.87 MPa for mature slash pine trees. Tang et al. (1999) reported that soil moisture supply was sufficient for loblolly pine foliar gas exchange when predawn ψ were higher than -1.0 MPa. They have observed that photosynthesis decreased about 40% when daytime needle water potential of loblolly pine trees decreased to -2.3 MPa and approached zero when Ψ reached -3.0 MPa. In two different studies with loblolly pine seedlings, Teskey et al. (1986) and Seiler and Johnson (1988) observed stomatal closure at about -2.0 MPa.

Lower needle pressure potentials of April-planted trees compared to trees planted in earlier months indicates that if there is a drought, early-planted trees with their better established root systems may have an advantage in delaying development of water stress over late-planted trees. Growth data also showed that earlier planted trees had the greatest height and diameter among trees planted at different dates; whereas April-planted trees had the least height and diameter, even into their third growing season.

Despite the fact that soil moisture was lower on 2003 measurement dates compared to those of 2002, no separation in needle ψ observed among planting months suggest that water stress might be more critical in earlier years after planting.

Net photosynthesis rates, transpiration, and stomatal conductance did not differ considerably among planting months or stock types during any of the measurement sessions in either year. Radoglou et al. (2003) did not find any significant difference in photosynthesis in chestnut seedlings planted on different dates (December to March). Also they reported that, in general, photosynthesis rates of Italian oak (*Quercus frainetto* Ten.) seedlings planted on different dates were comparable (Radoglou et al. 2003).

Measured carbon isotope compositions were within the range of $\delta^{13}C$ values for terrestrial C_3 plants and were close to those found by Mortazavi and Chanton (2002) (-27.3‰ to -28.5‰) for slash pine needles and by Parasolova et al. (2003) (-25‰ to -29.5‰) for slash pine and pine Caribbean pine hybrids.

April trees had less negative $\delta^{13}C$ values (i.e. closer to zero) and higher time-integrated WUE than did September and January trees in their first growing season. This is presumably caused by lower g_s due to susceptibility of April trees to water loss. Higher needle ψ of April-planted trees in their second growing season compared to those trees planted in the other months also validate this situation. Lower g_s will reduce the A_n/g_s leading to less negative foliar $\delta^{13}C$.

However since earlier planted trees have better established root systems they will have a relatively better water supply and their stomata might be open to a greater extent increasing A_n/g_s and resulting in more negative $\delta^{13}C$. Many studies have described the relationship between $\delta^{13}C$ and water status of plants (Fotelli et al. 2001). Lack of significant difference in $\delta^{13}C$ values among trees planted in different months in the second growing season might be due to their better established root systems in the second season. This might also have been caused by the greater water availability (due to higher precipitation) during the second growing season (2002) as indicated by more negative $\delta^{13}C$ values as compared to the first growing season (2001).

The higher $\delta^{13}C$ values observed on site III compared to Site I might be explained by the better drainage and the relatively dryness of Site III. Less negative $\delta^{13}C$ values have been reported for trees on drier sites compared to wetter sites (Parasolova et al. 2003), and seedlings adapted to drier sites exhibited less negative $\delta^{13}C$ values (Cregg and Zhan 2001).

On the drier site, containerized rooted-cuttings showed more carbon isotope discrimination in the first growing season compared to BRS, suggesting that CRC has an advantage in water supply presumably due to faster root establishment. The destructive sampling data also indicated greater root and aboveground biomass (but lower root:shoot ratios) of CRC over BRS in the first year. Containerized stock's performance over BRS on drier sites has been well documented (Anderson et al. 1984, Boyer 1988, South and Barnett 1986).

Trees planted in April 2001 had higher needle ψ on the first measurement session in summer 2002. However 2000-2001 trees did not show any $\delta^{13}C$ differences among different planting months in their second growing season.

This is probably because needle ψ is an indication of one point in the season and might not reflect the different conditions during the entire season.

Greater root weights of containerized trees planted September through January and the greater needle and stem weights September through March compared to BRS indicated that CRC had been accumulating root and aboveground biomass considerably faster than BRS in the first year following planting. Therefore, CRC might have an advantage in resisting possible stress conditions. Early planted September trees also had substantially higher biomass compared to March and April trees in the following May. After 72 weeks in the ground, September trees still had significantly higher above- and belowground biomass than those planted in other months suggesting that planting early in September provides a growth advantage at the end of the first growing season. However, 47 to 72 weeks after, the below and aboveground biomass differences disappeared among trees planted November through March indicating that extending the planting season as late as March might result in comparable growth to that of November and January trees. Yet, April-planted trees still had substantially lower dry weights than those planted in other months indicating that extending the planting season to April might not be advantageous. This is consistent with other studies with loblolly pine (Dierauf 1976, South and Barnett 1986, Barnett and McGilvray 1993).

At the May 30, 2001, sampling, root:shoot ratios of BRS planted in January, March and April 2001 were higher compared to CRC planted on the same dates. This might indicate that BRS go through longer periods of planting shock compared to CRC. The balance between root and shoot reflects limiting environmental factors (Johnson 1990). Favorable water and nutrient levels generally cause shifts in biomass allocation from roots to shoots whereas when these are limiting the opposite is observed (Kozlowski and Davies 1975, Johnson 1990, Dewald et al. 1991). Since both stock types grew on the same environment, perhaps CRC with its faster root growth was able to provide a more favorable water balance, thus resume shoot growth soon after planting which lead to lower root:shoot ratios. Seven weeks after planting, visual observation of greater number of and longer white feeder roots in containerized April stock compared to BRS also confirmed this.

Either lack of differences between the two stock types or greater dry weights for the BRS in late planting in April compared to greater dry weights for CRC in the earlier planted months are likely to be the cause of the stock type x planting month interaction observed at the May 2001 sampling.

CHAPTER IV
SUMMARY

This study showed that CRC had steadily higher survival rates compared to lower and highly variable survival rates of BRS in all planting dates and locations through three planting seasons. This indicates that it is possible to extend the planting season by planting CRC.

Generally, there was a negative relationship between soil moisture at the time of planting and first-year survival of BRS planted September through March in 2001-2002 and 2002-2003 planting seasons, whereas the opposite was observed only for BRS planted in April 2002 and 2003. Survival of CRC was affected very little by the variation in soil moisture.

Containerized stock also had higher early height and diameter growth than did BRS. However, three years after planting the size differences between stock types disappeared or became negligible. The early growth differences among trees planted from September through March also decreased after three years although September trees were tallest. However, growth from the April-planted trees was poor compared to trees planted in other months even after three years; thus, April is not recommended for planting.

Bare-root seedlings allocated more belowground biomass relative to its size, although they were smaller than the CRC in the first year. This suggests that CRC is able to allocate its biomass in the aboveground components in a more efficient manner than the BRS under similar site conditions.

Net photosynthesis rates did not differ considerably between stock types or among planting dates in the second and third growing seasons. Late-planted April trees had higher $\delta^{13}C$ values, higher WUE and lower above and belowground biomass allocation in the first growing season compared to earlier planted trees. Although differences in $\delta^{13}C$ values among the planting dates disappeared in the second growing season, April trees still had the lowest above and belowground biomass. This suggests that later-planted trees are more susceptible to environmental stresses compared to early-planted ones.

This study indicates that it is possible to extend the planting season to as early as September and as late as March by using CRC.

LITERATURE CITED

American Forest & Paper Association. 1998. Sustainable forestry for tomorrow's world. 1998 progress report on the American Forest & Paper Association's sustainable forestry initiative (SFI) program. AF&PA, Washington, DC. p. 20.

American Forest & Paper Association. 2001. Sustainable forestry initiative (SFI) program brochure. AF&PA, Washington, DC. p.11.

Anderson, R. L., J. L. Knighten, and H. R. Powers. 1984. Field survival of loblolly and slash pine seedlings grown in trays and ray leach containers. Tree Plan. Notes. 35(2):3-4.

Aycock, O. 1974. Field performance of containerized seedlings in the southern region. *In* R. W. Tinus, I. Stein, and W. E. Balmer (ed.). Proc. of North American containerized for. tree seedling symposium; 1974 August 26-29; Denver, CO; Great Plains Agri. Council Publ. 68:321-328.

Balmer, W. E., and H. L. Williston. 1974. Guide for planting the southern pines. USDA For. Serv. South Area State and Private For. Pub. p. 17.

Barnett, J. P. 1984. Relating seedling physiology to survival and growth in container-grown southern pines. *In* Proc. of the phys. work. group tech. sess., SAF national convention. October 16-20, 1983; Portland, OR. Seedling physiology and reforestation success; M.L. Duryea, and G.N. Brown (ed.). Martinus Nijhoff Publishers, Dordrecht, Netherlands. p.157-176.

Barnett, J. P., and J. B. Brissette. 1986. Producing southern pine seedlings in containers. USDA For. Serv., South. For. Exp. Sta. Gen. Tech. Rep. SO-59 p. 71.

Barnett, J. P., and J. M. McGilvray. 1993. Performance of container and bareroot loblolly pine seedlings on bottomlands in South Carolina. South. J. App. For. 17:80-83.

Barnett, J. P., and J. M. McGilvray. 2000. Growing longleaf pine seedlings in containers. Native Plants J. 1(1):54-58.

Barney, C. W. 1951. Effects of soil temperature and light intensity on root growth of loblolly pine seedlings. Plant Phys. 26:146-163.

Boyer, W. D. 1988. Effects of site preparation and release on the survival and growth of planted bareroot and container grown longleaf pine. Georgia For. Commission, Georgia For. Res. Pap., 76 Aug. 1988. p. 1-7.

Brissette, J. C., F. V. Linde, and J. P. Barnett. 1983. Producing, storing and handling quality slash pine seedlings. Proc. of symposium held at the Univ. of Florida. School of For. Res. and Cons. Gainesville, FL. p.150-164.

Cregg, B. M., and J. W. Zhang. 2001. Physiology and morphology of *Pinus sylvestris* seedlings from diverse sources under cyclic drought stress. For. Ecol. Manage. 154:131-139.

Demers, C., and Long A. 2000. Longleaf pine regeneration. IFAS pub.. School of For. Res. and Cons. Univ. of Florida. Gainesville, FL. SS-FOR-13. p. 5.

Derr, H. J., and W. F. Mann Jr. 1977. Bedding poorly drained sites for planting loblolly and slash pines in southwest Louisiana. Res. Pap. SO-134. New Orleans, LA; USDA For. Serv., South. For. Exp. Sta. p. 5.

Dewald, L., T. L. White, and M. L. Duryea. 1991. Growth and phenology of seedlings of four contrasting slash pine families in ten nitrogen regimes. Tree Phys. 11:255-269.

Dierauf, T. A. 1976. Fall planting and storage using non-dormant seedlings. *In* Proc. of 1976 Southeastern Area Nurserymen's Conf. Lantz C.W. (ed.) Cosponsored by Alabama For. Commission, South Carolina State Commission of For., and USDA For. Serv. Southeast Area, State and Private For., Atlanta, GA. p. 30-36.

Donovan, L. A., and J. R. Ehleringer. 1994. Potential for selection on plants for water-use efficiency as estimated by carbon isotope discrimination. Am. J. Bot. 81(7):927-935.

Dougherty, P. M. and M. L. Duryea. 1991. Regeneration: an overview of past trends and basic steps needed to ensure future success. *In* Forest regeneration manual. M. L Duryea, and P. M. Dougherty (ed.) Kluwer Academic Publishers. Dordrecht, Netherlands. p. 3-7.

Drew, A. P., and F. T. Ledig. 1980. Episodic growth and relative shoot:root balance in loblolly pine seedlings. Ann. of Bot. 45:143-148.

Duncan, W. H., and M. B. Duncan. 1988. Trees of the southeastern United States. The Univ. of Georgia Press, Athens, GA. p. 322.

Ezell, A. W., and D. J. Moorhead. 2000. Planting southern pines; A guide to species selection and planting techniques. Mississippi State Univ. Ext. Serv. p. 19.

Flanagan, L. B., and J. R. Ehleringer. 1998. Ecosystem-atmosphere interactions: Interpreting signals of change using stable isotope ratios. Trends Ecol. Evol. 13:1-10.

Foster, G. S., C. C. Lambeth, and M. S. Greenwood. 1987. Growth of loblolly pine rooted cuttings compared with seedlings. Can. J. For. Res. 17:157-164.

Fotelli, N. M., A. Geßler, A. D. Peuke, and H. Rennenberg. 2001. Drought affects the competitive interactions between *Fagus sylvatica* seedlings and an early successional species, *Rubus fruticosus*: responses of growth, water status and $\delta^{13}C$ composition. New Phytol. 151:427-435.

Frampton, J., F. Isik, and B. Goldfarb. 2002. Effects of nursery characteristics on field survival and growth of loblolly pine rooted cuttings. South. J. App. For. 26(4):207-213.

Goodwin, O. C. 1976. Summer-planted loblolly and longleaf pine tubelings outgrow 1-0 nursery seedlings in North Carolina. J. For. 74:515-516.

Goodwin, O. C. 1980. Containerized longleaf pine seedlings survive better and grow faster than nursery stock on sandhill sites after five growing seasons. For. Note 42. North Carolina Div. For. Resour. Raleigh. p. 6.

Greenwood, M. S., G. S. Foster, and H. V. Amerson. 1991. Vegetative propagation of southern pines. *In* Forest regeneration manual. M. L Duryea, and P. M. Dougherty (ed.) Kluwer Academic Publishers. Dordrecht, Netherlands. p.75-85.

Guldin, R. W. 1981. Outlook for container grown seedlings in reforestation of southern woodlands. For. Farmer XLI (2):16-17.

Haywood, J. D. 1995. Responses of young slash pine on poorly drained to somewhat poorly drained silt loam soils to site preparation and fertilization treatments. USDA For. Serv. South. For. Exp. Sta. Res. Note. SO-379. p. 5.

Haywood, J. D., A. E. Tiarks, and E. S. Shoulders. 1990. Loblolly and slash pine height and diameter are related to soil drainage in winter on poorly drained silt loams. New For. 4:81-96.

Jenkins, D. H., and J. E. Johnson. 1999. Sustainable forestry: a guide for Virginia forest landowners. Virginia Coop. Ext. Pub. N. 420-139. p. 1-30.

Johnson, J. D. 1990. Dry-matter partitioning in loblolly and slash pine: effects of fertilization and irrigation. For. Ecol. Manage. 30:147-157.

Kozlowski, T. T., and W. J. Davies. 1975. Control of water balance in transplanted trees. Arboriculture 1:1-10.

Kramer, P. J., and T. T. Kozlowski. 1960. Physiology of trees. McGraw-Hill, New York, p. 642.

Kramer, P. J. 1962. The role of water in tree growth. *In* Tree growth. Kozlowski, T. T. (ed.) Ronald Press, New York, p. 171–182.

Lantz, C.W. 1996. A guide to the care and planting of southern pine seedlings. management bulletin R8-MB39. USDA For. Serv. South. Region. Atlanta, GA: p. 30.

Lohrey, R. E., and S. V. Kossuth. 1990. *Pinus elliottii* Engelm. Slash Pine. *In* Burns, Russell M.; Honkala, Barbara H., Technical Coordinators. Silvics of North America. Volume 1. Conifers agriculture handbook 654. USDA For. Serv. Washington, DC: p. 338-347.

Long, A. J. 1991. Proper planting improves performance. *In* Forest regeneration manual. M. L Duryea, and P. M. Dougherty (ed.) Kluwer Academic Publishers. Dordrecht, Netherlands. p. 303-320.

Malinauskas, A., and V. Sukhotskas. 1996. Establishing plantations at different times in the growing season. Lesovedenie. Litovskii Institut Lesa, Girionis, Lithuania. p. 85-88.

Mann, W. F. 1977. Status and outlook of containerization in the South. J. App. For. 75:579-581.

Marion, P. S., and A. A. Alm. 1986. Performance of fall- and spring-planted bareroot and container grown red pine (*Pinus resinosa* Ait.). Tree Plant. Notes 37(2):24-26.

McCulley, R. D. 1950. Management of natural slash pine stands in the flatwoods of south Florida and north Florida. Circular No. 845. USDA. Washington, DC: p. 57.

McCune, B. 1988. Ecological diversity in North American pines. Am. J. Bot. 75(3):353-368.

Mcgrath, D. A., M. L. Duryea. 1994. Initial moisture stress, budbreak and two-year performance of three morphological grades of slash pine seedlings. New For. 8:335-350.

McKee, W. H., and E. Shoulders. 1970. Depth of water table and redox potential of soil affect slash pine growth. For. Sci.16:399-402.

Monk, C. D. 1966. Root-shoot dry weights in loblolly pine. Bot. Gazette 127(4): 246-248.

Mortazavi, B., and J. P. Chanton. 2002. Carbon isotopic discrimination and control of night-time canopy $\delta^{18}O\text{-}CO_2$ in a pine forest in the southeastern United States. Global Biogeochemical Cycles, 16(8):1-13.

Myers, B.J. 1988. Water stress integral—a link between short-term stress and long-term growth. Tree Phys. 4:315–323.

O`Leary, M. H. 1993. Biochemical basis of carbon isotope composition. *In* Stable isotopes and plant carbon-water relations. Ehleringer J.R., A.E. Hall, and G.D. Farquhar (ed.) Academic Press Inc. San Diego, CA. p. 555.

Okafo, O. A., and J. W. Hanover. 1978. Two-year performance of barerooted and containerized trembling and bigtooth aspen seedlings. Tree Plant. Notes. 25:24-28.

Owston, P. W., and W. I. Stein. 1974. A suggested method for comparing containerized and bareroot seedling performance on forest lands. USDA For. Serv. Pacific NW For. and Range Exp. Sta. Res. Note PNW-222. p.12.

Parasolova, N. V., Z. H. Xu, K. Lundkvist, G. D. Farquar, M. J. Dieters, S. Walker, and P. G. Saffigna. 2003. Genetic variation in foliar carbon isotope composition in relation to tree growth and foliar nitrogen concentration in clones of the F1 hybrid between slash pine and Caribbean pine. For. Ecol. Manage. 172:145-160.

Ponton, S., J. L. Dupouey, N. Breda, F. Feuillat, C. Bodenes, and E. Dreyer. 2001. Carbon isotope discrimination and wood anatomy variations in mixed stands of *Quercus robur* and *Quercus petraea*. Plant, Cell Environ. 24:861-868.

Radoglu, K., Y. Raftoyannis, and G. Halivopoulos. 2003. The effects of planting date and seedling quality on field performance of *Castanea sativa* Mill. and *Quercus frainetto* Ten. seedlings. For. J. 76(5):569-578.

SAS Institute Inc. 1997. SAS/STAT User's Guide, Release 6.12 Edition. Cary, NC p.1028.

Schultz, P. R. 1997. Loblolly pine: The ecology and culture of loblolly pine (*Pinus taeda* L.) Agricultural Handbook 713. USDA For. Serv., Washington, DC.

Seiler, J. S., and J. D. Johnson. 1988. Physiological and morphological responses of three half-sib families of loblolly pine to water-stress conditioning. For. Sci., 34(2):487-495.

Shaw, D. V. 1985. Containerized seedlings a good buy. For. Farmer 45(1):11-12.

Sheffield, R. M., H.A. Knight, and J.P. McClure. 1983. The slash pine resource. *In* The managed slash pine ecosystem. E. L. Stone (ed.). Proc. of a symposium; 1981 June 9, Univ. of Florida, Gainesville, FL. p. 4-23.

Sloan, J. L., L. H. Jump, and R. A. Ryker. 1987. Container-grown ponderosa pine seedlings outperform bareroot seedlings on harsh sites in southern Utah. USDA For. Serv., Intermountain Res. Sta. Res. Pap. INT-384. p. 13.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry: The principles and practice of statistics in biological research. W. H. Freeman and Co. San Francisco, CA. p. 776.

South, D. B., and J. B. Barnett. 1986. Herbicides and planting date affect early performance of container-grown and bareroot loblolly pine seedlings in Alabama. New For. 1:17-27.

Stelzer, H. E., G. S. Foster, V. Shaw, and J. B. McRae. 1998. Ten-year growth comparison between rooted cuttings and seedlings of loblolly pine. Can. J. For. Res. 28:69-73.

Tang, Z. J. L. Chambers, and J. P. Barnett. 1999. Characterization of optimum physiological responses of field-grown loblolly pine. P. 409-415. *in* J. D. Haywood (ed.). Tenth Biennial Southern Silvic. Res. Conf. USDA For. Serv. Southeastern For. Exp. Sta. Gen. Tech. Rep. SRS-30. p. 618.

Teskey, R. O. J. A. Fites, L. J. Samuelson, and B. C. Bongarten. 1986. Stomatal and non-stomatal limitations to net photosynthesis in *Pinus taeda* L. under different environmental conditions. Tree Phys. 2:131-142.

Teskey, R. O., H. L. Gholz, and W. P. Cropper, Jr. 1994. Influence of climate and fertilization on net photosynthesis of mature slash pine. Tree Phys. 14:1215-1227.

Tinus, R. W., K. E. Burr, N. Atzmon, and J. Riov. 2000. Relationship between carbohydrate concentration and root growth potential in coniferous seedlings from three climates during cold hardening and dehardening. Tree Phys. 20: 1097-1104.

Vogel, J. G. 1993. Variability of carbon isotope fractionation during photosynthesis. *In* Stable isotopes and plant carbon-water relations. J. R. Ehleringer, A. E. Hall, and G. D. Farquhar (ed.). Academic Press Inc. San Diego, CA. p. 29-46.

Walker, L.C., and B.P. Oswald. 2000. The southern forest: geography, ecology, and silviculture. CRC Press, Boca Raton, FL. p. 332.

Wakeley, P. C. 1954. Planting the southern pines. USDA For. Serv. Agri. Monog. 18:233.

Weber, J., and H. Stelzer. 2000. Operational rooted cuttings in southern pines. *In* National proceedings: For. and Cons. Nur. Assoc. 1999, 2000, and 2001. Proc. Dumroese, R.K., L.E. Riley, and T.D. Landis, technical coordinators. RMRS-P-24. USDA For. Serv. Rocky Mountain Res. Sta. Ogden, UT. p. 91-92.

Yeiser, J. L., and J. L. Paschke. 1987. Regenerating wet sites with bareroot and containerized loblolly pine seedlings. South J. Appl. For. 11(1):52-55.

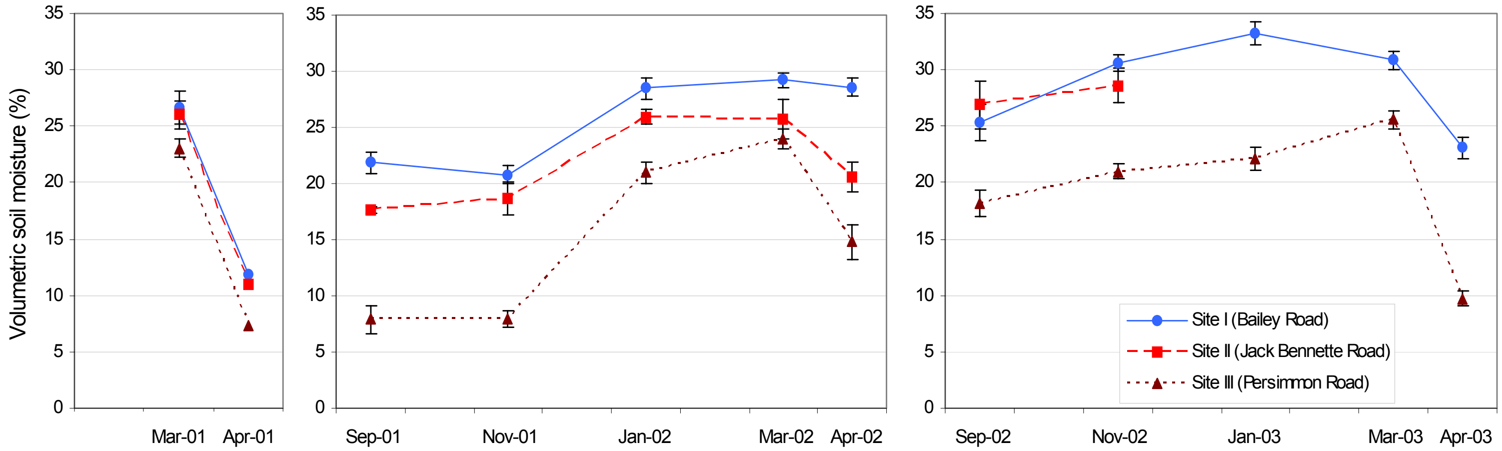
APPENDIX 1

APPENDIX 1. Soil descriptions of the study sites.

Site Number	Site Name	Soil Series	Taxonomic Class	Depth to Argillic Horizon (cm)	Landscape position	Drainage
I	Bailey Road Site	Caddo-Messer	Fine-silty, siliceous, thermic Typic Glossaqualfs-Coarse-silty, siliceous, thermic Haplic Glossudalf	30 -50	Level flat	Poorly-drained
II	Jack Bennette Road Site	Caddo-Messer	Fine-silty, siliceous, thermic Typic Glossaqualfs- Coarse-silty, siliceous, thermic Haplic Glossudalf	15 - 30	Level flat	Poorly-drained
III	Persimmon Road Site	Caddo-Messer	Fine-silty, siliceous, thermic Typic Glossaqualfs-Coarse-silty, siliceous, thermic Haplic Glossudalf	15 - 30	Broad ridge	Somewhat poorly-drained

APPENDIX 2

APPENDIX 2. Volumetric soil moisture content (0-15 cm) at the time of planting on three sites. Error bars represent one standard error.



APPENDIX 3

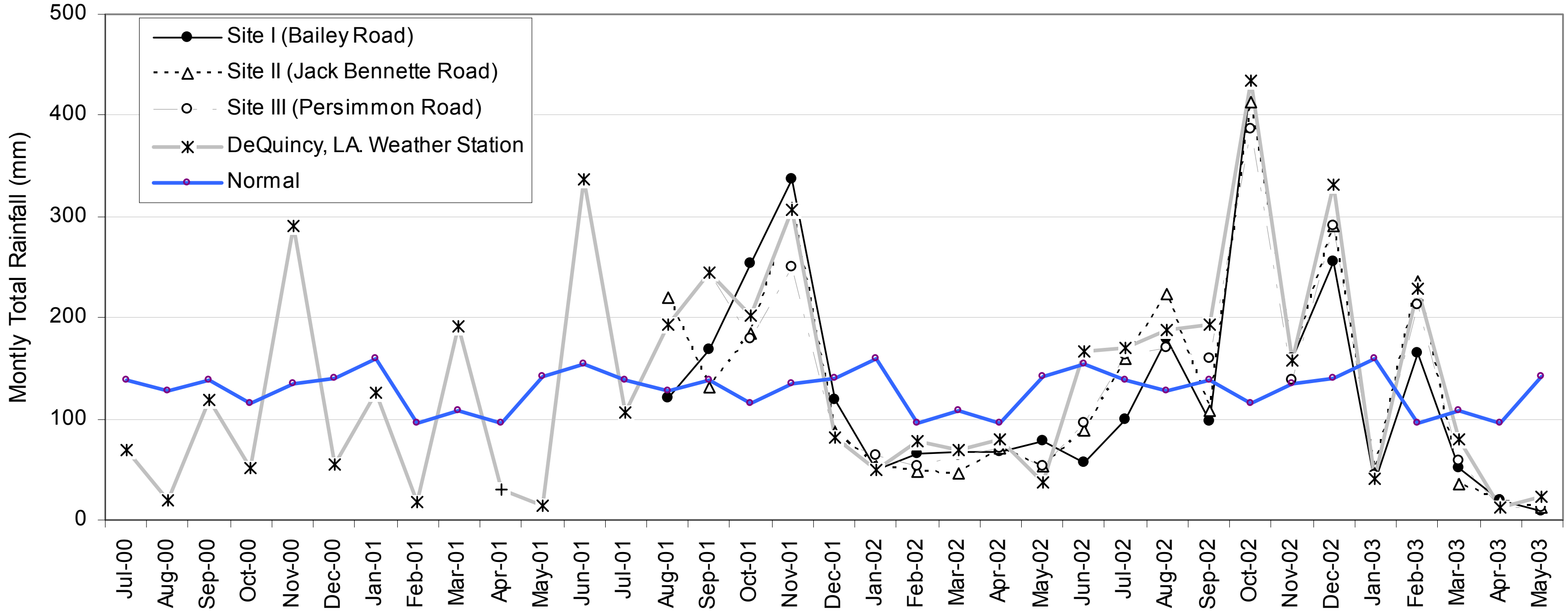
APPENDIX 3. Regression equations and statistical significance of the relationship between volumetric soil moisture content at the time of planting and first-year survival of bare-root seedlings and containerized rooted cuttings.

	Bare-root seedlings				Containerized rooted cuttings			
Planting date	Model	R^2	N	Significance	Model	R^2	N	Significance
				2001				
March 2001			30	ns			30	ns
April 2001			30	ns			30	ns
				2001-2002				
September 2001	%SURV = 79.2 + 1.4 VSM - 0.17 VSM^2	0.563	30	***	%SURV =98.1 + 0.48 VSM - 0.02 VSM^2	0.356	30	**
November 2001			30	ns			30	ns
January 2002	%SURV = -96.4 + 16.5 VSM -0.36 VSM^2	0.287	30	**			30	ns
March 2002	%SURV = 117.3 - 1.67 VSM	0.146	30	*			30	ns
April 2002	%SURV = - 12 + 6.87 VSM - 0.12 VSM^2	0.662	30	***			30	ns
				2002-2003				
September 2002	%SURV = 78.8 + 0.16 VSM - 0.05 VSM^2	0.341	30	**			30	ns
November 2002	%SURV = 199 - 5.1 VSM	0.715	30	***			30	ns
January 2003	%SURV = 283.2 - 13.3 VSM + 0.21 VSM^2	0.305	20	*			20	ns
March 2003	%SURV = 331.9 - 14.1 VSM + 0.15 VSM^2	0.549	20	***			20	ns
April 2003	%SURV = - 68.7 + 11.8 VSM - 0.27 VSM^2	0.690	20	***			20	ns
2001-2002			150	ns			150	ns
2002-2003	%SURV = - 50.2 + 11 VSM -0.25 VSM^2	0.282	120	***			120	ns

*: P<0.05; **: P<0.01; ***: P<0.001. N: Sample size; each sample represents average of five soil moisture measurements on a plot and survival of fifteen BRS or CRC.

APPENDIX 4

APPENDIX 4.Total monthly rainfall recorded on DeQuincy, LA and three study sites. Rainfall among sites did not differ significantly. Normal is the 30-year rainfall average for the months recorded between 1971 and 2000 at DeQuincy weather station. (National Climatic Data Center website, http://cdo.ncdc.noaa.gov/ancsum/ACS).



+ April 2001 total rainfall data was not available in DeQuincy. Data shown for this month was recorded at a nearby station in DeRidder, LA.

APPENDIX 5

APPENDIX 5. Air temperature, relative humidity at the planting dates and planting weather classification.

	Air temperature (°C)		Minimum RH (%)
Planting date	Maximum	Minimum	
	2000-2001		
22-Sep-2000	28.3 M*	22.2 N*	#
9-Nov-2000	26.1 M*	5.6 N*	#
11-Jan-2001	7.8 N*	2.2 N*	#
12-Mar-2001	21.7 N*	12.8 N*	#
26-Apr-2001	25.0 M*	6.7 N*	#
	2001-2002		
21-Sep-2001	34.5 C*	19.8 N*	50.3 N*
9-Nov-2001	25.6 M*	10.5 N*	38.6 M+
11-Jan-2002	16.1 N*	11.0 N*	71.7 N*
7-Mar-2002	24.2 M*	11.3 N*	54.0 N*
18-Apr-2002	29.4 C*	17.7 N*	54.7 N*
	2002-2003		
12-Sep-2002	35.2 C*	20.1 N*	44.1 M+
7-Nov-2002	21.8 N*	3.8 N*	38.1 M+
9-Jan-2003	23.5 M*	15.9 N*	68.3 N*
6-Mar-2003	8.4 N*	6.9 N*	97.1 N*
17-Apr-2003	30.9 C*	16.3 N*	39.0 M+

*Air temperature categories for planting (Normal; 1-23 °C, Marginal; 23-29 °C, and Critical < 0 °C or >29 °C).
+Relative humidity categories for planting (Normal; >50 %, Marginal; 30-50 % and Critical; <30 %).
#The weather data in 2000-2001 were obtained from a nearby weather station in DeQuincy. However minimum relative humidity data were not available in DeQuincy. 2001-2002 and 2002-2003 data were recorded at Jack Site II (Bennette Road site)

VITA

Alper Akgül

Birth place: Zile, Turkey

205 sokak No:25 Buca İzmir Türkiye / Turkey

Education

Ph.D. in Forestry, Texas A&M University, College Station, 2004.

M.Sc. in Agriculture, Ege University, Institute of Natural and Applied Sciences, Izmir, Turkey, 2000.

B.S. in Forest Engineering, Istanbul University, Faculty of Forestry, Istanbul, Turkey, 1993.

Professional Experience

Research Assistant at the Department of Forest Science, Texas A&M University, College Station, 2000 to 2004.

Forest Engineer at Izmir Forest Soil Laboratory, Turkish Ministry of Forestry, Izmir, Turkey, 1995 to 2000.

Forestry Coordinator and Specialist Advisor to Aerial Firefighting Team, Directorate of Forestry, Izmir, Turkey, summer 1998.

Forest Engineer at the Forest District Office, Menemen, Turkey 1994.